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AFFDL-TR-78-38
PART 3

INTERACTIVE COMPOSITE JOINT DESIGN

PROGRAMMING MANUAL

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APRIL 1978

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A computing technique was developed to determine the feasibility of combining the several batch computer programs for the analysis of composite joints into one interactive computer program utilizing graphics display. This approach proved successful and produced a design tool for the analysis of bolted or bonded composite joints. The program utilizes the software package provided by TEKTRONIX for the graphics display. The user works at

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the remote on-line graphics terminal in conjunction with the main computing facilities which contain the program.

The final report discusses the summary, conclusion, and recommendations of the work performed. The User's Manual and Programming Manual discuss the input, output, and function of the program.

FOREWORD

This report is one of a series that describes work performed by Douglas Aircraft Company, McDonnell Douglas Corporation, 3855 Lakewood Boulevard, Long Beach, California, 90846, under the Interactive Composite Joint Design Program. This work was sponsored by the U. S. Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, under contract F33615-76-C-3058.

This report is divided into three parts. Part 1 is entitled "Final Technical Report", part 2 is entitled "User's Manual", and part 3 is entitled "Programming Manual". The principle investigators and authors are M. K. Smith, C. G. Dietz and L. J. Hart-Smith.

Mr. James R. Johnson was the Air Force Project Manager during the conceptual phase of this project. During conduct of the program, Mr. Johnson was succeeded by Lt. K. Schrader (AFFDL/FBRA).

This report was submitted to the Air Force on 15 April 1978, and covers work performed during the period April 1976 through April 1978.

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SECTION I

COMPUTER PROGRAM DESCRIPTION

INTRODUCTION

The programming manual describes the computer program and analytical description of the analysis routines. Section I covers all aspects of the program regarding hardware, software, files, system implementation and the program source.

The JOINT program is essentially a collection of composite joint analysis routines that have been interfaced with graphics input/output routines. Provisions have been made for the utilization of data files for saving solutions and printing on hardcopy.

OPERATIONAL CONSIDERATIONS

Hardware

The JOINT program utilizes the Tektronix PLOT10 software routines, and may be executed on a hardware that can emulate the Tektronix 4014/4015. The screen size must be sufficient to handle 132 characters/line and 64 lines/page.

The 4014 terminal may utilize a joystick or thumbscrews to position the screen crosshairs. If there is a graphics tablet available, the user is given the option to use that instead of the crosshairs. The above devices are used to locate and transmit screen coordinates for the selection of various options.

Scope

Joint Types

Bolted: Balanced Double-lap
Unsupported Single-lap
Supported Single-lap
Stepped-lap

Bcnded: Double-lap

Unsupported Single-lap

Supported Single-lap

Stepped-lap

Scarfed

Materials

For the bolted joints, the user may use graphite-epoxy materials with either 25% or 37.5% zero-degree plies. Also, the user may choose either steel or titanium bolts.

For the bonded joints, the user inputs the properties of the adherend and the adhesive, thereby placing no restrictions on materials, including metal.

PROGRAM CONSIDERATIONS

Language

The source was developed using standard FORTRAN.

Standards

CDC standards were used. The availability of 60-bit words made the need for double-precision unnecessary. If this program is adapted to installation with a word size less than 60 bits, double-precision accuracy should be used, as explained in the analysis routines.

The overlay of program routines was accomplished through the use of CDC OVERLAY. Refer to figure 1 for the routine overlay map.

Data Files

The first two files identified on the CDC program card are for the SAVE and PRINT files, respectively. These on-line disk files have default local file names of TAPE1 and TAPE 2, which the user may change local equivalencing.

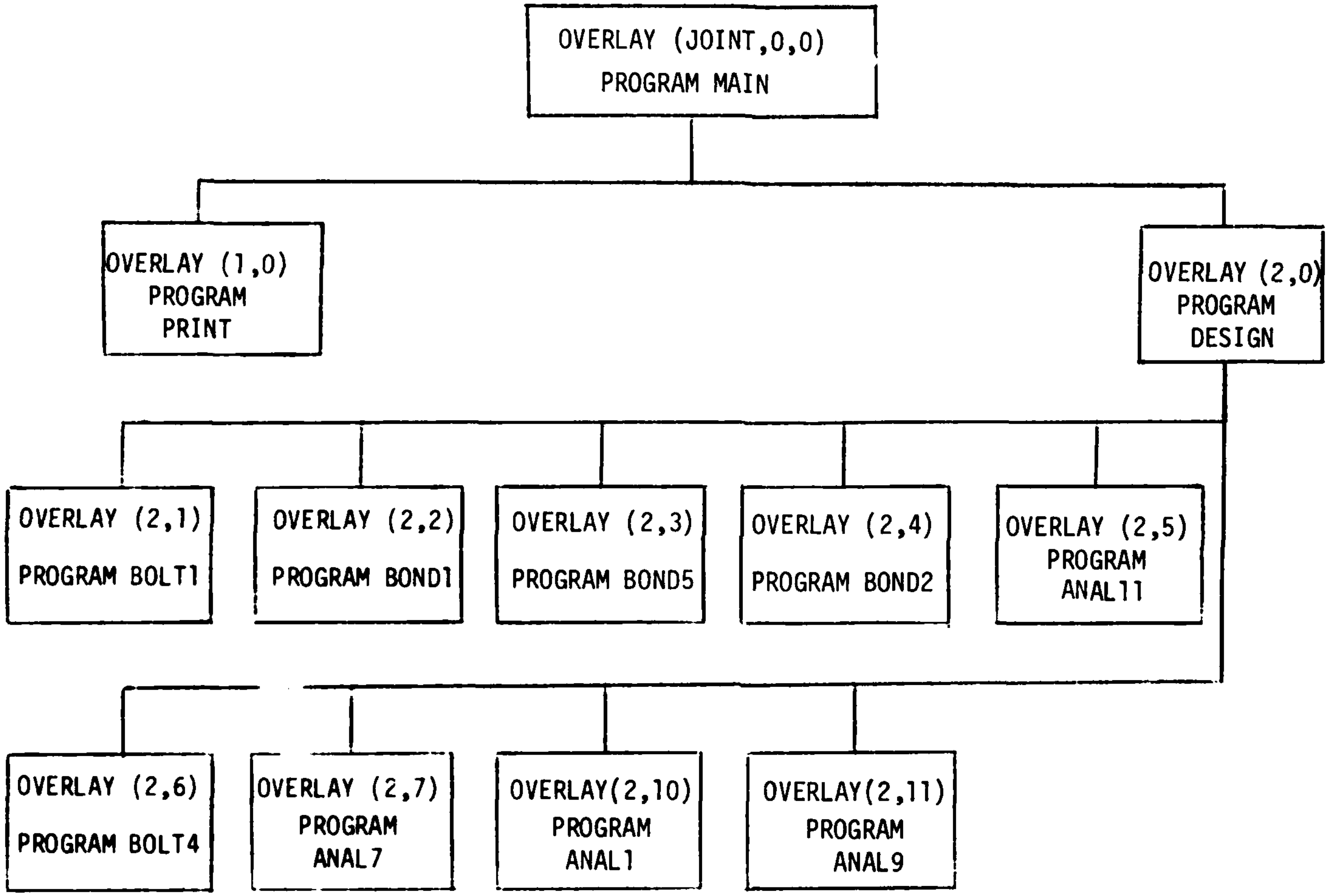


Figure 1. Routine overlay map

Save File

The SAVE file is for the accumulation of user-designated solutions that may be used as input to a problem, or written t- either the PRINT file or the terminal screen. The solution input and output data is contained in the program's WORK array. When the user electes to save the solution, the program positions the SAVE file at the end of data, and the following data is output using unformatted write statements.

```
WRITE (1) NDT, TMPNAM, IT
WRITE (1) NENT, (WORK(I), I = 1, NENT)
```

where:

NDT = sequential solution number on the file

TMPNAM = 8-character name

IT = joint type

NENT = number of items in the WORK array

WORK = array containing solution I/O data

The end-of-data on the save file is indicated by NDT=999 in the first record.

The variable ND is used to indicate the position of the read/write disk head. ND is set equal to the solution number of the previous I/O operation. If a read of the save file is indicated, the desired solution number is compared with ND; if the desired number is not greater than ND, file 1 is rewound before the search is made. For a save, the file is positioned at the end of data.

The ANAME and ITYPE arrays contain the name and type of all solutions on the SAVE file, and are dimensioned at 100. Therefore a 100 solution limit to the number of solutions contained on the SAVE file is due to these array dimensions. A consolidation feature is available to the user to purge solutions from the SAVE file. All except the indicated solutions to be purged are copied to a temporary file then back to unit 1. The solution numbers are resequenced, and corresponding changes are made to the ANAME and ITYPE arrays.

The user may elect to select a solution on the SAVE file to use as input for a problem. The ITYPE array is searched for types corresponding to the type of problem selected, and only those corresponding names from the ANAME array are displayed for user selection. After the selection is made, the SAVE file is searched for that solution, and the data read into the WORK array.

The user may also elect to output selected solutions contained on the SAVE file. The entire ANAME array is displayed for the user to make selections. During execution the SAVE file is searched for a solution, the data is read to the WORK array, and the appropriate output routine is called; this procedure is repeated for each selected solution name.

The user may wish to input a SAVE file that was constructed from a previous execution of the program. A file that has been cataloged on CDC can be read but not written on. Therefore a copy to a local file is usually required. When on old SAVE file is input to the program, the ANAME and ITYPE arrays are constructed from the data in the first record of each solution on the file. The user is then able to add new solutions, read input data from the file, and print from the file.

Print File

The PRINT file is for the formatted output of solutions. It is rewound and created new each session. The user may write the solution to a problem after execution and display; the appropriate output routine is called, and the input and output data contained in the WORK array is written to the PRINT file. If the solution is output to the SAVE file, the user may use the SELECTIVE OUTPUT mode to select desired solutions to be output to the PRINT file. During execution each solution indicated is read from the SAVE file to the WORK array and the appropriate output routine called to write the solution to the end of the PRINT file.

Standard ASA carriage control is used for the formatted writes. The maximum output to a page is 110 characters per line, and 64 lines per page.

After the user's session, the print file may be used for on-line viewing, or hardcopy printing via a batch job.

Graphics

In addition to the program being interactive, it is executable only on the Tektronix 4014/4015 hardware noted previously. The routines, from PLOT10 Terminal Control System User's Manual for release 2.0/3.0, are used to plot drawings, change character size, clear the page, and obtain screen coordinates.

Refer to the System Implementation subsection for the library used to supply the PLOT10 routines.

The use of both Terminal Control System (TCS) commands with Fortran I/O statements must be handled with care. TCS commands and Fortran WRITE's use different buffers which cannot be controlled. Care must be taken to follow these guidelines:

- o Before calling a TCS command, call RECVR if any WRITE's precede it.
- o Before calling Fortran WRITE's, call ANMODE if TCS commands precede it.

SYSTEM IMPLEMENTATION

Update, Compile, and Load Procedure

During development of the program, the procedure outlined in Figure 2 was used to facilitate updates. The three separate tasks are update, compile, and load. The absolute file JOINT is created through execution of this batch job; it then may be executed on-line (see Figure 5).

JOINTUPD is the update file used for the CDC UPDATE command. It contains the source and subsequent updates. The system-produced SOURCE file is not saved.

JOINTLGO is the LGO file output from COPYL. It contains the compilation of all previous routines, plus those compiled in the current run. It is cataloged only because it is required for input to COPYL.

JOINT is the absolute file for execution on-line.

When new routines are added that do not exist on the JOINTLGO file, a full compile is executed to create a new JOINTLGO file. Figure 3 shows a typical setup used for a full source compile. This batch run also produces a new JOINTUPD file from the source file.

Field Length Map

Figure 4 shows the size of the routines in the program. The name of each subroutine is included.

On-Line Operation

Figure 5 shows the procedure to execute the JOINT program. In this example, the user is assigning local files A and B to the SAVE and PRINT files.

SYSTEM OVERVIEW

Data Flow Description

The program has been structured so the WORK array is used for the temporary storage of all input and output data for an analysis. The input data is either read into the WORK array, or the values are equivalenced to WORK. The WORK array is common to all analysis routines where the input is received and output stored in the WORK array. All output (OUT) subroutines use data passed in the WORK array.

If re-analysis is selected, the user may edit entries in the existing WORK array, or copy a SAVE file solution to the WORK array for edit.

The bonded stepped-lap analysis routine reuses many of its variables. Therefore, it was necessary to use a temporary WK array to store the I/O items.

INSTRUCTION	COMMENTS
ATTACH(OLOPL,JOINTUPO)	OLD UPDATE FILE
REQUEST(NEWFILE,*PF)	FOR NEW UPDATE FILE
UPDATE(P,F,N=NEWFILE)	FULL UPDATE FOR UPD FILE
RETURN(OLDPL,COMPILE)	
REWIND(NEWFILE)	
CATALOG(NEWFILE,JOINTUPD,RP=999)	
UPDATE(Q,P=NEWFILE)	COMPILE ONLY UPDATED DECKS
REWIND(COMPILE)	
REQUEST(LGO,*PF)	
FIN(I=COMPILE,OPT=2,R=3)	COMPILE NEW DECKS
RETURN(NEWFILE,COMPILE)	
ATTACH(OLDLGO,JOINTLGO)	PREVIOUS LGO FILE
REQUEST(COPYLGO,*PF)	
REWIND(OLDLGO,COPYLGO)	
COPYL(OLDLGO,LGO,COPYLGO)	REPLACE OBSOLETE DECKS
CATALOG(COPYLGO,JOINTLGO,RP=999)	NEW LGO FILE
RETURN(OLDLGO,LGO)	
REQUEST(ABS,*PF)	FOR ABSOLUTE JOINT FILE
REWIND(COPYLGO,ABS)	
ATTACH(L,TEKLIB,ID=654321,SN=AFIT)	LIBRARY OF TEKTRONIX SUBR
LIBRARY(L)	
MAP(ON)	
LOAD(COPYLGO)	
NOGO(ABS)	CREATE ABSOLUTE FILE
REWIND(ABS)	
CATALOG(ABS,JOINT,RP=999)	

```
*EOR
*IDENT MKS0109

        ****   DECK OF UPDATES TO FILE   ****

*EOR
*COMPILE OUT9,PRINT,ANAL1,BOND1,ANAL9,ESCARF,PSCARF
```

Figure 2, Update, Compile, and Load Procedure

INSTRUCTION	COMMENTS
ATTACH(OLDPL,JOINTUPD)	OLD UPDATE FILE
UPDATE(P,F,S)	FULL UPDATE, TO SOURCE FILE
RETURN(COMPILE,OLDPL)	
REQUEST(NEWFILE,*PF)	FOR NEW UPDATE FILE
UPDATE(F,I=SOURCE,N=NEWFILE)	OUTPUT NEW SOURCE FILE
RETURN(SOURCE)	
REWIND(NEWFILE,COMPILE)	
CATALOG(NEWFILE,JOINTUPD,RP=999)	
REQUEST(LGO,*PF)	FOR NEW LGO FILE
FIN(I=COMPILE,OPT=2,B=LGO,R=3)	COMPILE THE INPUT FILE
RETURN(NEWFILE,COMPILE)	
CATALOG(LGO,JOINTLGO,RP=999)	NEW LGO FILE
REQUEST(ABS,*PF)	FOR ABSOLUTE JOINT FILE
REWIND(LGO,ABS)	
ATTACH(L,TEKLIB,ID=654321,SN=AFIT)	LIBRARY OF TEKTRONIX SUBR.
LIBRARY(L)	
MAP(ON)	
LOAD(LGO)	
NOGO(ABS)	CREATE ABSOLUTE FILE
REWIND(ABS)	
CATALOG(ABS,JOINT,RP=999)	
*EOR	
*IDENT MKS0203	

**** DECK OF UPDATES TO FILE ****

*EOF

Figure 3. Full Compile Procedure

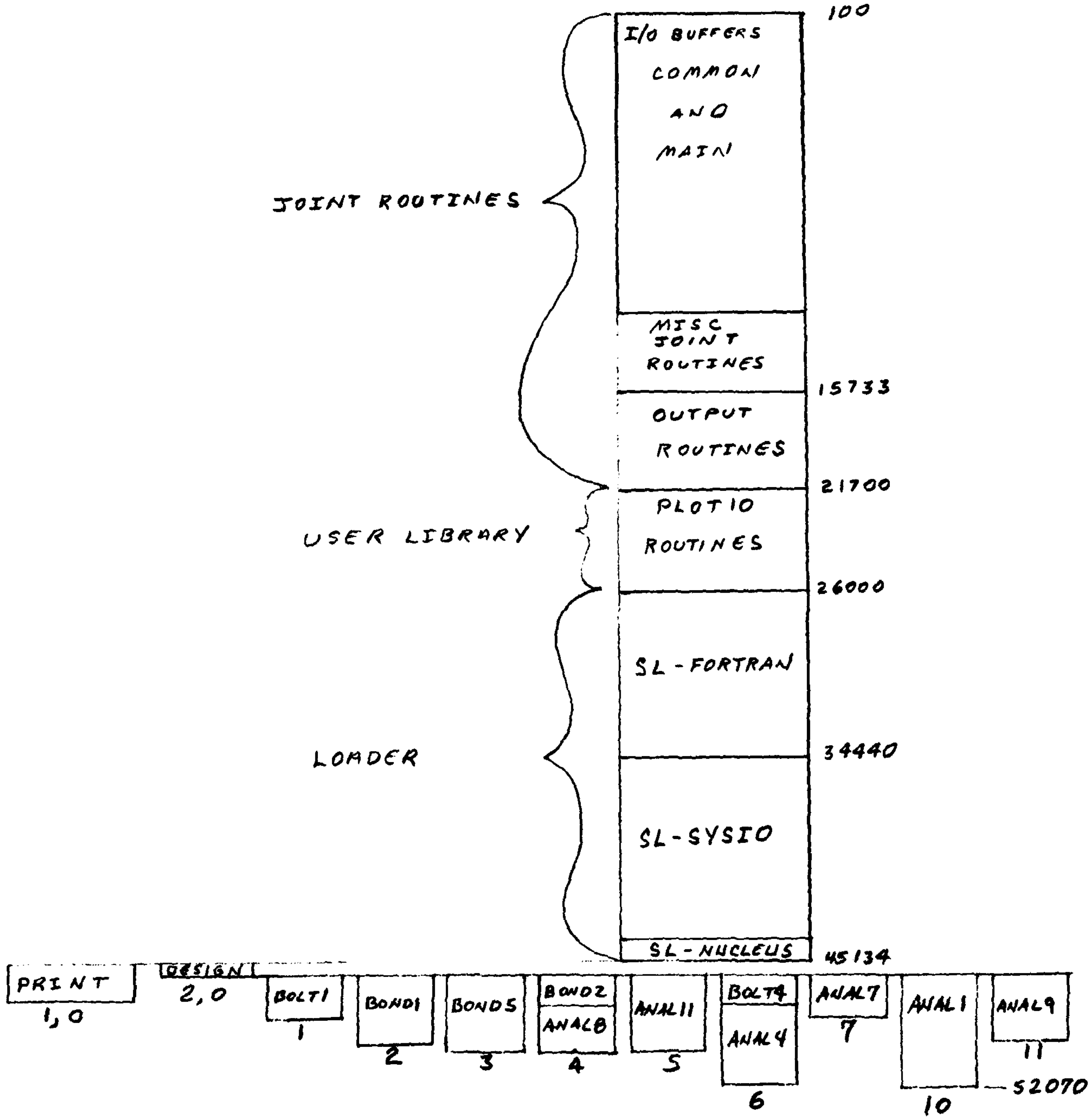


Figure 4. Field length map

```
COMMAND- screen,132.                         set  screenlength to 132 char./line

COMMAND- attach,x,mkstape1.                  a save file from a previous session.

 PF CYCLE NO. = 004
COMMAND- request,a,*pf.                      permanent save file for this session.

COMMAND- request,b,*pf.                      permanent print file for this session.

COMMAND- rewind,x,a

COMMAND- copy,x,a.                           copy file for use during this session.

COMMAND- attach,joint,id=d700209.            JOINT program to be executed.

 PFN IS
 JOINT
 PF CYCLE NO. = 027
COMMAND- joint,a,b.                          request execution of JOINT program.
                                             local file A equivalenced to TAPE1 default.
                                             local file B equivalenced to TAPE2 default.

DOES SAVE FILE CONTAIN DATA? (1=YES, 0=NO): 1

  16 SOLUTIONS ON SAVE FILE.

IS GRAPHICS TABLET TO BE USED FOR SCREEN LOCATIONS? (1=YES, 0=NO): 0
```

Figure 5. Joint Execution Procedure

Subroutine COPYWK copies the WK array to the WORK array before WK is reused or altered.

Save File

All data in the WORK array is written to the SAVE file in subroutine SAVE. The number of entries in the WORK array, NENT, is set in the analysis input routine. Whenever the user selects to SAVE the analysis, the file is positioned at the END record before writing the data, unformatted.

Reading data from the SAVE file to the WORK array for editing is accomplished in subroutine EDSEL (EDit SELection).

Subroutine PRINT also reads the SAVE file to WORK before calling the output routines, and before writing to TAPE 3 during consolidation.

Program Routine List

The following is an alphabetical list of the program routines.

ANAL	COPYWK	OUT1	READ1
ANAL11	DBLB	OUT4	SAVE
ANAL7	DESIGN	OUT7	SELECT
ANAL8	EDSEL	OUT8	SID
ANAL9	ESCARF	OUT9	STPLP
BOLT1	FKBOLT	OUT11	TH
BOLT4	FKPROP	OPTION	WDMAX
BOND1	FPROP	PCT	WDMIN
BOND2	INIT	PCTSTP	WT
BOND5	MAIN	PRINT	WTSL
BOX	NAME	PSCARF	WWT
BOXNO		QUADMN	XYLOC

Common Blocks

The common blocks used throughout this program are summarized below with the variables which comprise them.

Unlabeled	NDT, NC, NCT, ITYPE(100), IUNIT2
/BLK1/	TMPNAM(2), ANAME(100,2)
/BLK2/	ND
/BLK3/	NOCONV
/BLOCK/	PROP(6), FBOLT(4)
/CONSOL/	ICON
/COPY/	KSTART(4)
/DBLBLT/	MAT, PROP(6), FBOLT(4), TNOM, DD, MM, FX, ED, FTUO, FSTN, LLF(9), FFS(9)
/IANAL/	IA
/TABFLG/	ITAB
/WK/	WK(800)
/WORK/	WORK(2500)

Variable List and Description

General

Below is a list and description of frequently used variables. Since the variable names used in the various analysis routines are unique, the variables and their equivalance location in the WORK array are listed separately. The description of the routines covers the variables particular to each.

ANAME	Array of analysis names contained on SAVE file.
IA	/IANAL/ common flag for input routines which are overlaid by analysis routines.
ICØN	/CONSOL/ common flag for PRINT routine.

IDVGT	Flag to denote divergent analysis for bonded stepped lap solution.
IEND	999 flag signifying end of data on SAVE file.
IT	Analysis type.
ITAB	/TABFLG/ flag used in XYLOC for use of tablet or crosshair.
ITYPE	Array of analysis types contained on SAVE file.
IUNIT2	Set = 1 to print message upon EXIT that PRINT file contains data.
IX	Integer X screen coordinate.
IY	Integer Y screen coordinate.
KC	Denotes column number of detected name on screen (from 1 - 10).
KD	Denotes row number of detected name on screen (from 1 - 10).
KT	Analysis type read from SAVE file.
KN	Analysis number.
KSTART	Array of starting locations within WORK for bonded stepped-lap data.
NC	Current analysis type being processed.
ND	/BLK2/last analysis number processed on SAVE file for tracking file position.
NDT	Total number of solutions on SAVE file.
NENT	Number of entries in WORK array.
NU	Unit number.
TMPNAM	Temporary contents for current analysis name.
WK	Temporary work array for bonded stepped-lap routines.
WØRK	Array for all input and output data for a given solution.

Analysis Input/Output Variables

The following subsections list and describe the various I/O variables used for each analysis, and their equivalent location in the WORK array. The number in parentheses is the dimension.

Bolted Double- and Single-Lap Joints

variable	work location	description
NX	1	input joint load (lb./in.)
MATL	2	joint material code
KBØLT	3	bolt type code
FSTN	4	tension failure factor of safety
TEMP	5	joint temperature (F.)
W	6	bolt spacing within a row (in.)
D	7	bolt diameter (in.)
T	8	composite plate thickness (1/2 joint thickness)
M	9	number of bolt rows (output)
WX	10	joint weight (lb./in.)
MM	11	absolute value of M
PB(9), IPB(9)	12	decimal and % values of load transferred
FS(9)	21	margins of safety
LF(9)	30	failure mode codes
FX	39	computed joint load if NX = 0
MO	40	input number of bolt rows

Bolted Stepped-lap Joint

variable	work location		description
M	1		number of steps
FX	2		applied joint load
TEMP	3		joint temperature
FSTN	4		tension failure factor of safety
KBØLT	5		bolt type code
MATLI	6		inner material code
MATLØ	7		outer material code
B(9)	8	for each bolt row	step lengths
D(9)	17		bolt diameters
W(9)	26		bolt spacing
WD(9)	35		W/D ratios
TI(9)	44		inner material thickness
TØ(9)	53		outer material thickness
PB(9)	62		% of load transferred by bolts
PTI(9)	71		% of load retained by inner plate
PTØ(9)	80		% of load retained by outer plate
FS(9)	89		margins of safety
LF(9)	98		failure mode codes
F	107		critical load value
IRØW	108		critical row number

Bonded Double-Lap and Supported Single-Lap

variable	work location	description
K	1	load type
PLØAD	2	input applied load
ØVRLAP	3	input overlap length
(ADHESIVE PROPERTIES)		
GAMMAX	4	max. shear strain
ETA	5	thickness
TEMP	6	operating temperature
TEMPC	7	cure temperature
TAUEL	16	elastic shear strength
GEL	17	linear elastic shear modulus
TAUP	18	elastic-plastic shear strength
GADHSV	19	non-linear elastic shear modulud
EPEEL	8	peel modulus
SGMAPL	20	peel strength
(ADHEREND PROPERTIES)		
THICKI	9	thickness (inner)
THICKØ	21	thickness (outer)
EINNER	10	Young's modulus (inner)
EØUTER	22	Young's modulus (outer)
GNUINR	11	Poisson's ratio (inner)
GNUØTR	23	Poisson's ratio (outer)
ALPHAI	12	coeff. of thermal expansion (inner)
ALPHAØ	24	coeff. of thermal expansion (outer)
FI	13	yield strength (inner)
FØ	25	yield strength (outer)

variable	work location	description
ETRNSI	14	transverse modulus (inner)
ETRNSØ	26	transverse modulus (outer)
SGTRNI	15	transverse strength (inner)
SGTRNØ	27	transverse strength (outer)
FCYINR	28	compressive yield strength (inner)
FCYØTR	31	compressive yield strenghh (outer)
FSYINR	29	shear yield strength (inner)
FSYØTR	32	shear yield strength (outer)
FTYINR	30	tensile yield strength (inner)
FTYØTR	33	tensile yield strength (outer)
(OUTPUT DATA)		
ØLAP	34	either optimum or specified overlap
ØVLAP	35	optimum overlap length
GAMEL	36	linear elastic adhesive shear strain
GAMMAE	37	non-linear elastic adhesive shear strain
GAMMAP	38	plastic adhesive shear strain
GAMMA	39	elastic-plastic adhesive shear strain
STRBND	40	elastic-plastic adhesive shear strength
ELBND	41	linear elastic adhesive shear strength
STRSAV	42	non-linear elastic adhesive shear strength
STRINR	43	inner adherend strength
STRØTR	44	outer adherend strength
BNDPL	45	limit load due to adhesive peel or interlaminar adherend tension

variable	work location	description
TAUMAX	46	maximum elastic adhesive shear stress
IPRNT	47	stress analysis print flag
JCRTND	48	critical end for strength computation
ICRTND	49	critical end for stress analysis
FACTØR	50	number of bond surfaces
TMPBND	51	adhesive shear strength for given overlap

Bonded Unsupported Single-Lap

variable	work location	description
PLØAD	1	input applied load
ØLAP	2	input overlap length
(ADHESIVE)		
ETA	3	thickness
GAMMAX	4	maximum shear strain
TAUEL	5	elastic shear strength
GEL	6	linear elastic shear modulus
TAUP	7	elastic-plastic shear strength
GADHSV	8	non-linear elastic shear modulus
SGMAPL	9	peel strength
EPEEL	10	peel modulus
(ADHEREND)		
THCKN	11	thickness
PØISSN	12	Poisson's ratio
SIGULT	13	ultimate yield strength

variable	work location	description
EYØUNG	14	Young's modulus
STRTRN	15	transverse strength
ETRNSV	16	transverse modulus
AKB	17	laminating factor
(OUTPUT DATA)		
STR	18	remote adherend tension strength
BNDGLD(7)	19	combined tension + bending
BNDSTE(7)	26	elastic shear strength of adhesive
STRBND(7)	33	plastic shear strength of adhesive
STRPL(7)	40	limit load due to peel or inter-laminar tension
SIGAVG	18	ave. applied stress remote from joint
SIGMAX(7)	19	max. induced adherend stress at edge of overlap
SIGBND(7)	26	peak adhesive shear stress
GAMBND(7)	33	peak adhesive shear strain
SIGBPL(7)	40	peak adhesive peel stress at edge of overlap

It is noted that the last two output groups occupy the same place in WORK. This is so because only one group of variables is computed, depending on PLOAD.

Bonded Scarf Joint

Since the same routine processes the input, refer to the bonded double-lap for input variable descriptions. The only differences are in the adherend variables below:

variable	work location	description
T1	9	thickness (left)
T2	21	thickness (right)
E1	10	Young's modulus (left)
E2	22	Young's modulus (right)
GNU1, G1	11	Poisson's ratio (left)
GNU2, G2	23	Poisson's ratio (right)
ALPHA1	12	coeff. of thermal expansion (left)
ALPHA2	24	coeff. of thermal expansion (right)
(OUTPUT DATA)		
STRNG1	34	remote strength of left adherend
STRNG2	35	remote strength of right adherend
STR1	36	remote stress in left adherend
STR2	37	remote stress in right adherend
ØVLAP(7)	38	array of overlap lengths
ELBND(7)	45	elastic adhesive shear strength
EEPBND(7)	52	transitional adhesive shear strength
EPBND(7)	59	plastic adhesive shear strength
BNDSTR(7)	66	peak adhesive shear stress
GAMBND(7)	73	peak adhesive shear strain
K1(7)	80	critical end - elastic
K2(7)	87	critical end - transitional
K3(7)	94	critical end - plastic
K4(7)	101	critical end - peak stress
SYM+2	108	code designating scarf joint for routine BØND1.

Bonded Stepped-Lap Variables

Due to the variable number of steps possible for the analyses performed, and the re-use of the various arrays after each analysis, a temporary WK array is used to equivalence the variables during analysis. Below is a description of all I/Ø variables, followed by tables showing their equivalent location in WK, and relative position in WØRK.

KT	no. of entries used in WØRK
SGNLD	load type (-1, 0, 1)
NSTEPS,NCHECK	number of steps
DELTMP	temperature differential
JTDBLR	joint or doubler flag
NSYM	flag for symmetrical stress distribution
IFACTR	single/double bond surface
ETA	adhesive thickness
TAUMAX	peak adhesive shear stress
G	elastic adhesive shear modulus
GAMMAX	maximum adhesive shear strain
GAMMAE	elastic adhesive shear strain
ALPHAØ	outer adherend coeff. of thermal expansion
ALPHAI	inner adherend coeff. of thermal expansion
NOUT	flag for CØPYWK
IDVGT	flag denoting divergent analysis
STEPL, STEP	step lengths
TAU	adhesive shear stresses
GAMMA	adhesive shear strains
DELTAØ	outer adherend displacement
DELTAI	inner adherend displacement
TØUTER	outer adherend load

TINNER	inner adherend load
THICKØ, THCKNØ	*outer adherend thickness*
THICKI, THICKNJ	inner adherend thickness
ETØTR	outer adherend extensional stiffness
ETINR	inner adherend extensional stiffness
STRØTR, STRGTR	outer adherend strength
STRINR, STRGNR	inner adherend strength

TABLE 1. BONDED STEPPED-LAP WK ARRAY

Variable	Dimension	WK Location
STEPL	20	1
THICKØ		21
THICKI		41
ETØTR		61
ETINR		81
STRØTR		101
STRINR		121
STEP	60	141
THCKNØ		201
THCKNI		261
TAU		321
GAMMA		381
DELTAØ		441
DELTAI		501
TØUTER		561
TINNER		621
STRGTR		681
STRGNR		741

TABLE 2. BONDED STEPPED-LAP WORK ARRAY

1	KT	Base values not dependent on step data.
2	SGNLD	
3	NSTEPS	
4	DELTMP	
5	JTDBLR	
6	NSYM	
7	IFACTR	
8	ETA	
9	TAUMAX	
10	G	
11	GAMMAX	
12	GAMMAE	
13	ALPHAØ	
14	ALPHAI	
15	NØUT	
16	NSTEPS	(a)
	STEPL	INPUT STEP DATA
	THICKØ	7 arrays dimensioned at NSTEPS (a)
	THICKI	
	ETØTR	
	ETINR	
	STRØTR	
	STRINR	
	NSTEPS	(b)
	IDVGT	ELASTIC ANALYSIS
	STEPL	11 arrays dimensioned at NSTEPS (b)
	THICKØ	
	THICKI	
	TAU	
	GAMMA	
	DELTAØ	
	DELTAI	
	TOUTER	
	TINNER	
	STRØTR	
	STRINR	
	NCHECK	(c)
	IDVGT	ELASTIC-PLASTIC ANALYSIS
	STEP	11 arrays dimensioned at NCHECK (c)
	THCKNØ	
	THCKNI	
	TAU	
	GAMMA	
	DELTAØ	
	DELTAI	
	TOUTER	
	TINNER	
	STRGTR	
	STRGNR	

TABLE 2. BONDED STEPPED-LAP WORK ARRAY (Continued)

NCHECK	(d)	
IDVGT STEP THCKNØ THCKNI TAU GAMMA DELTAØ DELTAI TØUTER TINNER	}	ELASTIC-PLASTIC ANALYSIS WITH INFINITE ADHEREND STRENGTH 9 arrays dimensioned at NCHECK (d)

JOINT PROGRAM ROUTINE DESCRIPTION

The following is a description of each of the JOINT routines which will include the following items:

1. Algorithm - an overall description and purpose of the routine.
2. Argument List - a list of the arguments passed to or from the calling routine.
3. Common - a list of the common areas.
4. Length - octal words
5. Subroutines Called - a list of externals. (PLOT10 routines excluded)
6. Subroutines Called By - a list of routines that call this routine.
7. Input/Output - a description of reads and writes.
8. Error Handling - a description of how this routine handles errors or error codes.
9. Flow Chart - a functional diagram of the main portions of the routine.
10. Symbol List - description of the unique variables used on this routine, not covered by the main variable list in the System Overview subsection.

ANAL

1. Algorithm - This routine analyzes the design of a bolted double-lap joint.

2. Argument List - X, F, FU, DFU, NF

3. Common - DBLBLT

4. Length - 341 Octal

5. Subroutines Called - FKPROP, FPROP, PCT.

6. Subroutines Called by - DBLB

7. Input/Output - None

8. Error Handling - None

9. Flow Chart - None

10. Symbol List -

A	FSU	GGMIN	MATL
BS	FTU	GMIN	MM
D	FTUO	I	NF
DD	FU	J	PB
DFU	FX	JMIN	PROP
ED	F2	KT1	T
F	F3	KT2	TNOM
FBOLT	F4	LF	W
FBR	G	M	WD
FT	GG	MAT	X
FSTN			

ANAL11

1. Algorithm - Bonded Stepped-lap analysis routine for joints and doublers.

This routine analyzes the input in the WORK and WK arrays and the output data passed back through WK.

There are two main analysis sections. The elastic analysis is from card 240 through card 490; the elastic-plastic analysis is from card 550

to card 960. To compute the potential bond strength of the elastic-plastic case, it is re-analyzed with the inner and outer material strengths set very high.

The routine attempts to reverse joint geometry automatically when the basic load carrying assumptions are backwards.

The two analysis sections use the same variable names and re-analysis with reversed ends if possible. Therefore, it is necessary to use the WK work array to store data; when the end of an analysis is reached, the routine calls COPYWK to copy the contents of the WK array to the WORK array for final disposition. ANAL11 keeps track of which analysis has been completed with NØUT.

NØUT

1	input data
2	elastic solution
3	elastic-plastic solution
4	El.-Pl. solution for bond strength

This is a self contained analysis routine that has been adapted from the elastic and elastic-plastic programs contained in the NASA Technical Report CR-112237.

2. Argument List - none

3. Common - WØRK and WK

4. Length - 2467 Octal

5. Subroutines Called - CØPYWK

6. Subroutines Called By - DESIGN (from BOND5)

7. I/Ø - none

8. Error Handling - When the time interval for convergence exceeds the arbitrary value of 10 CP seconds, an error message,

> INPUT ERROR. A STEP CONTAINS AN EXCESSIVELY HIGH
> G VALUE, AND/OR AN EXCESSIVELY LOW ET VALUE.

is displayed, the routine is exited with NØUT = 0.

9. Flow Chart - Figure 6.

10. Symbol List - Refer to the I/O variables for the bonded stepped-lap routines. All others are unique to this routine and are contained in a compilation listing.

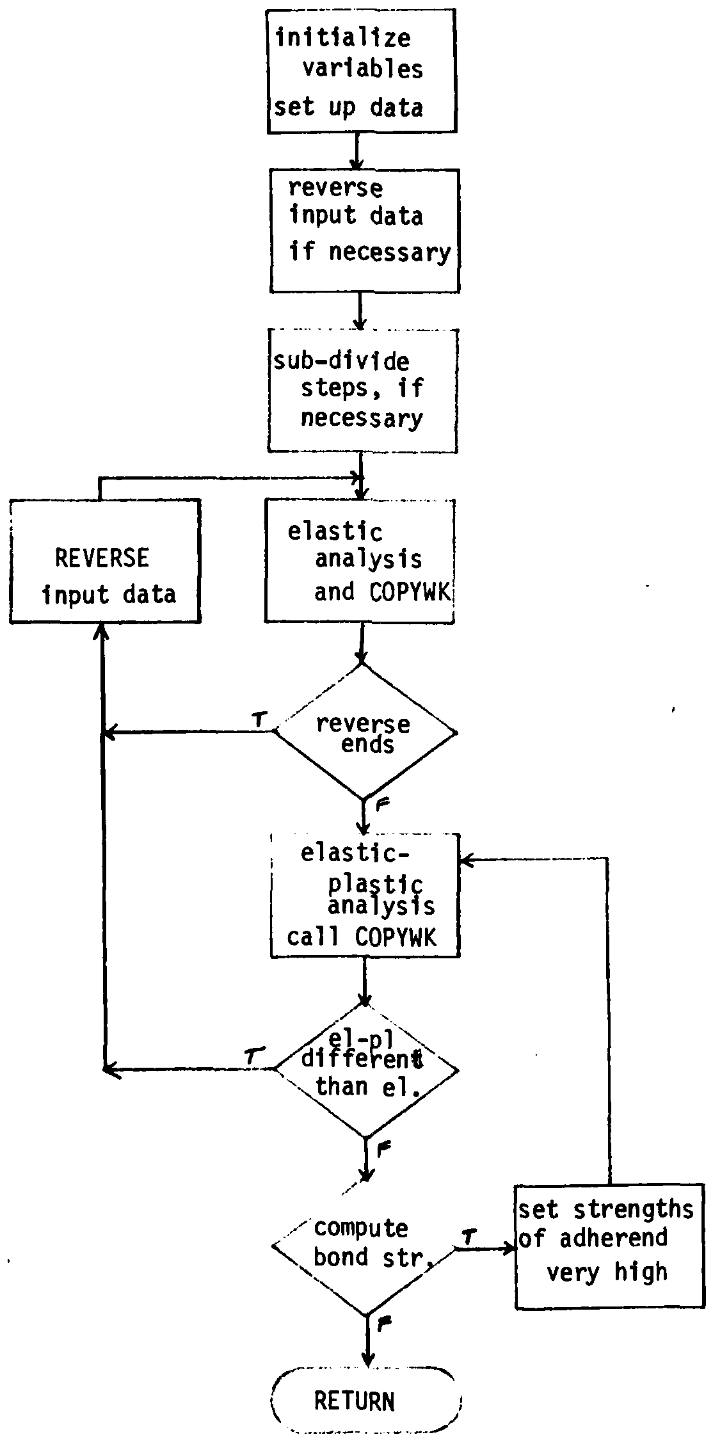


Figure 6. ANAL11 flow diagram

ANAL7

1. Algorithm - Bonded analysis for double-lap and supported single-lap joints, distinguished by the number of bond surfaces factor, ANBØND.

All I/O is passed through the WORK array. The re-use of the variable STRSAV has necessitated the storage of the original value in STRSA1, WORK(42).

This routine is the result of converting the non-dimensionalized version described in NASA Technical Report CR-112235.

Analysis of the joint automatically computes the adhesive and adherend strengths and the optimum overlap. If an overlap is specified by the user, the bond shear strength is computed. If the load is specified, the adhesive shear stress and strain is computed for either the specified overlap, or the optimum if the zero is specified.

2. Argument List - none.

3. Common - WORK.

4. Length - 1164 Octal.

5. Subroutines Called - none.

6. Subroutines Called By - DESIGN (from BOND1).

7. I/Ø - none.

8. Error Handling - If the joint load exceeds the bond and adherend strengths, the joint is overloaded, and IPRNT - 4 is a flag.

9. Flow Diagram - see Figure 7.

10. Symbol List - The I/Ø symbols are covered under the Routine Variables for bonded double-lap and supported single-lap joints. All others are unique to this routine and contained in a compilation listing.

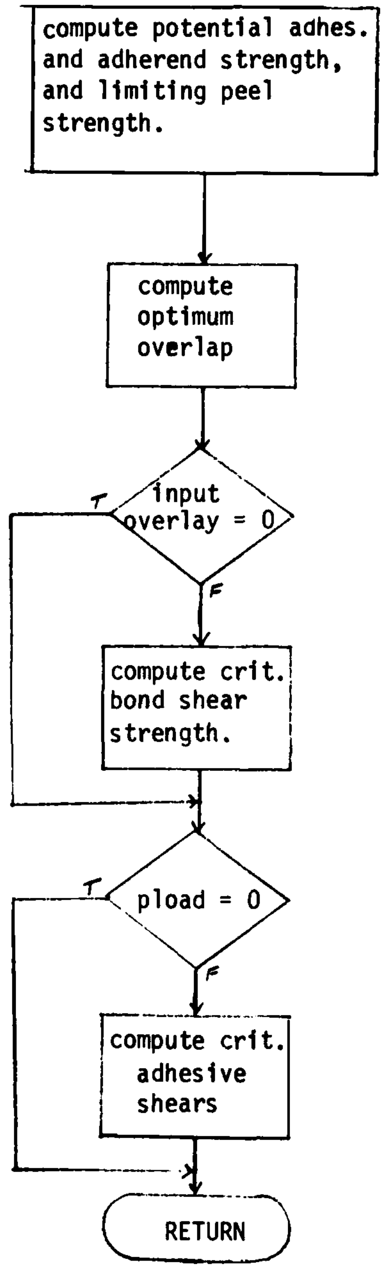


Figure 7. ANAL7 flow diagram

ANAL8

1. Algorithm - This is the analysis routine for the bonded unsupported single-lap joints.

If PLOAD is specified, this routine calculates the associated internal stresses; otherwise, the loads are determined at which various allowables are exceeded.

If an overlap is specified by the user, calculations are based on that overlap; otherwise, calculations are based on overlaps for a range of ℓ/t ratios for the given adherend thickness, t.

2. Argument List - none.

3. Common - WORK.

4. Length - 1216 Octal

5. Subroutines Called - none.

6. Subroutines Called By - BØND2.

7. I/Ø - none.

8. Error Handling - Failure to converge will print the appropriate message listing the iteration loops that were active. The flag NOCONV is set to 1 and returned to BOND2.

Asterisks are printed signifying strain failure.

9. Flow Diagram - see Figure 8.

10. Symbol List - Reference the subsection on the I/Ø variables for the bonded unsupported single-lap joint. All others unique to this routine are contained in the listing of variables for a compilation.

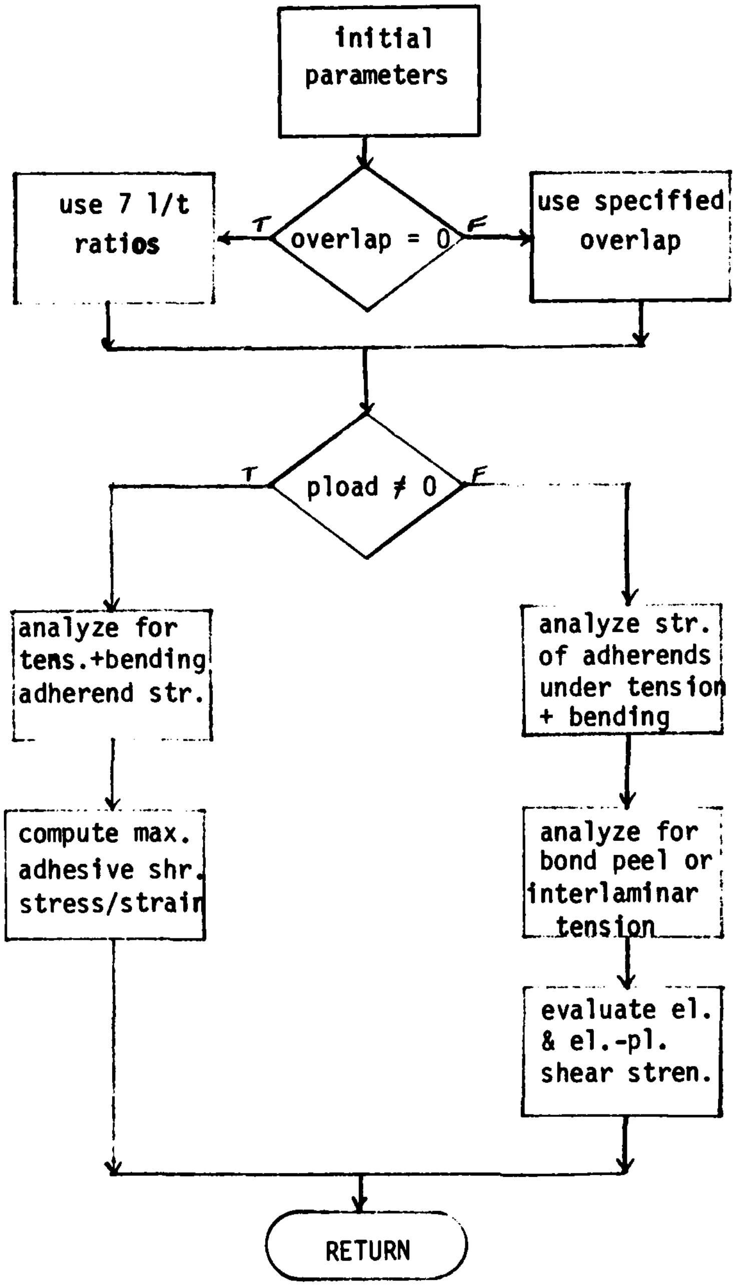


Figure 8. ANAL8 flow diagram

ANAL9

1. Algorithm - This routine analyzes a bonded scarfed joint with either two (symmetrical) or one (asymmetrical) bond lines.

If the overlap is zero, a range of 7 ℓ/t ratios are used for calculation.

For a specified load, maximum adhesive shear stresses and strains are calculated; otherwise, joint strengths are calculated.

If the extensional stiffness of the right end adherend is greater than the left, the ends are reversed and the user is so advised.

2. Argument List - FACTOR

3. Common - WORK

4. Length - 712 Octal

5. Subroutines Called - ESCARF; PSCARF

6. Subroutines Called By - BOND1

7. I/Ø - none.

8. Error Handling - If a joint is overloaded, output values are set high so as to print asterisks indicating failure cases.

9. Flow Diagram - See Figure 9.

10. Symbol List - Refer to the Routine Variables for the bonded scarf joint for I/Ø variables. The remainder are unique to this routine.

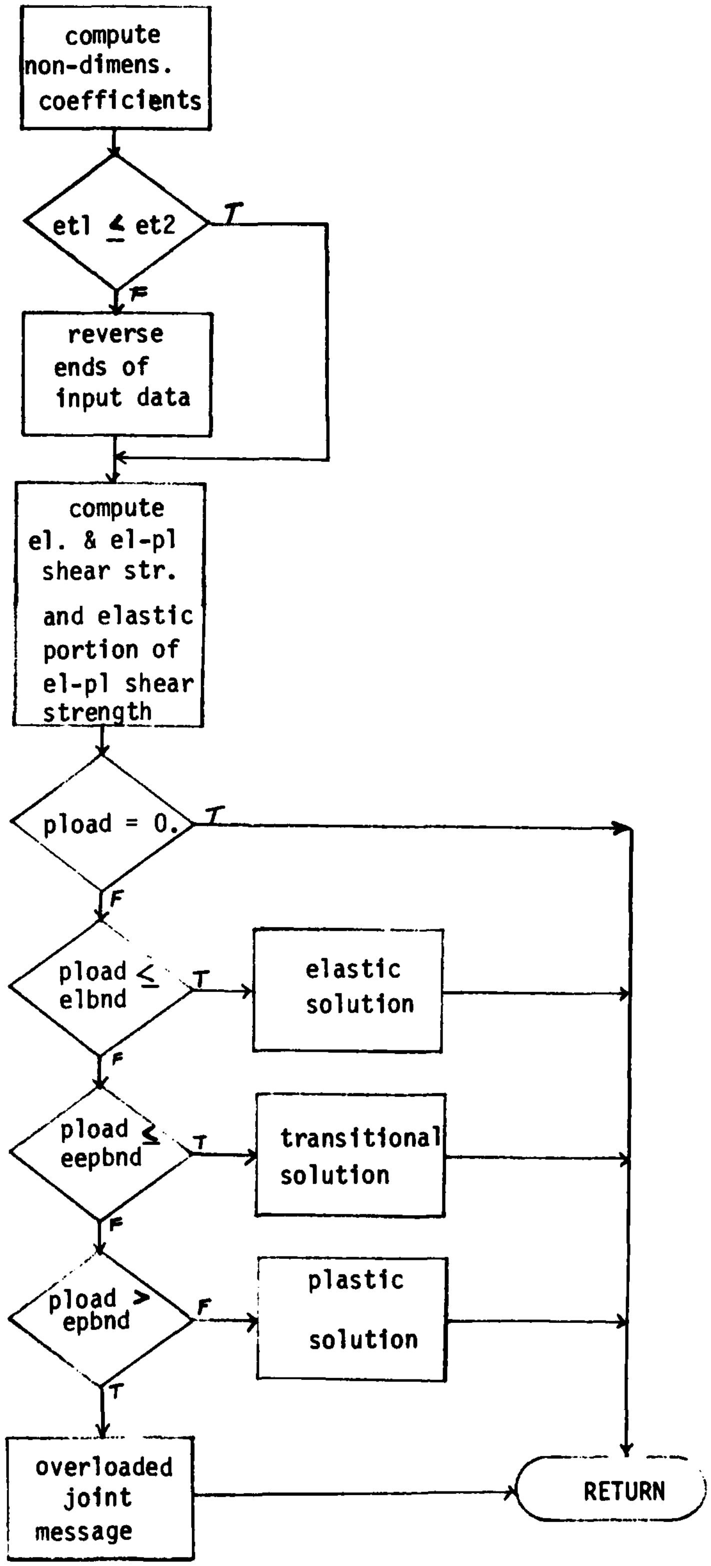


Figure 9. ANAL9 flow diagram

BOLT1

1. Algorithm - This is the input interface for the bolted double-lap and single-lap joints. All input is requested from the uer and passed to the analysis routines in the WORK array.

The SAVE file is not utilized for input due to the small number of constraints.

2. Argument List - none.

3. Common - blank (NDT, NC); BLK1 (TMPNAM), BLK2 (ND), WORK

4. Length - 743 Octal.

5. Subroutines Called - DBLB, NAME, OPTION, OUT1, SELECT

6. Subroutines Called By - DESIGN

7. I/Ø - Displays on unit 6 the header, typical drawing, constraint descriptions, and prompting messages. Reads from unit 5 the requested input data values.

8. Error Handling - none.

9. Flow Diagram - not necessary.

10. Symbol List - The following is a description of unique variables for this routine. Refer to the previous subsection on Routine Variables for others.

DIS	overlap length of 2 inches for picture
IDEL	screen x width of option boxes
II	return code from SELECT
IX	starting x coord. of first box
IY	starting y coord. of first box (top)
PT	(not used - argument from DBLB)
TH1	.2 in. outer material thickness for picture
TH2	.5 in. outer material thickness for picture

BOLT4

1. Algorithm - This is the input interface for the bolted stepped-lap joint option.

An existing solution on the SAVE file may be used as basic input for the WORK array. Editing is accomplished the same way as the RE-INPUT option.

This routine describes the input data required, then prompts the user for that data by list-directed reads. Processing will not continue until the read list has been satisfied. After all input is read in, the user is given options to RETURN to DESIGN, EXECUTE, or RE-INPUT data.

The RE-INPUT option for editing prompts the user for viewing and updating the problem. All items that are requested must be entered, even if only one item is different from the original. When editing is complete, the three options are displayed again.

After EXECUTE has been selected, the STPLP analysis routine is called. Upon completion the output routine is called and selections processed by SELECT. If re-analysis is to be performed, II is returned unchanged; if the user does not wish to re-analyze a SAVE file solution or the existing input from the previous analysis, all new data is requested.

2. Argument List - none.

3. Common - blank, BLK1, WORK

4. Length - 1132 Octal

5. Subroutines Called - EDSEL, INIT, NAME, OPTION, OUT4, SELECT, STPLP

6. Subroutines Called By - DESIGN

7. I/Ø - Displays on unit 6 the header, picture, required constraint description, and prompting messages.

The read statements are all list directed for the problem constraint data. Answers to questions must be the integer equivalent of YES and NO as displayed. This simplifies the testing of valid responses.

8. Error Handling - A maximum of nine steps is allowed. A message will be displayed if an invalid step or number of steps is entered, and correction requested.

9. Flow Diagram - see Figure 10.

10. Symbol List - The list and description below excludes the I/Ø variables common to the bolted stepped-lap routines, described in the Routine Variable subsection.

IDEL	input to OPTION as box width; returned as option code 1, 2 or 3
IE	return code from EDSEL
II	return code from SELECT
IREV	set - 1 to review input data
IX	starting X location of first option box
IY	starting Y location of first option box
MI	temporary storage of old no. of steps (M)

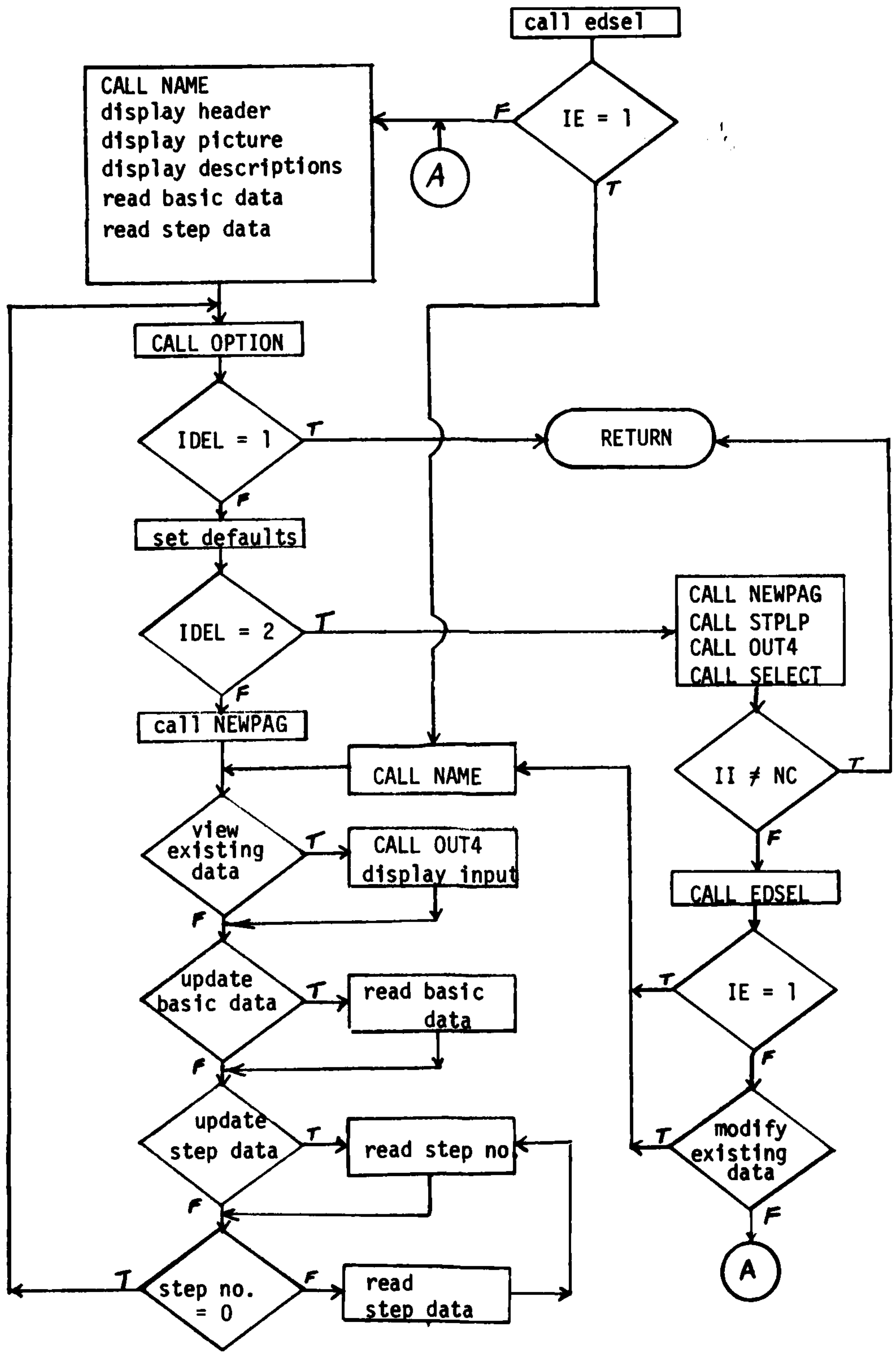


Figure 10. BOLT4 flow diagram

BONDI

1. Algorithm - This routine is the input interface for the analysis of bonded double-lap, supported single-lap, and scarfed joints.

The analyses are differentiated by setting the value of WORK(50) in DESIGN. ANAL7 uses WORK(50) for the number of bond surfaces (ANBOND), a value of 1 for the supported single-lap, and a value of 2 for the double-lap.

For the scarf joint, DESIGN sets WORK(50) equal to 3. The user is then asked to enter a 1 or 2 for the number of bond surfaces for the current scarf problem; this value, designated SYM, is passed to the analysis routine, ANAL9, through the argument list to flag the problem as asymmetrical (SYM = 1.), or symmetrical (SYM = 2.). A constant of 2 is added to SYM to give WORK(50) a value of 3 or 4 for use throughout BOND1. To simplify the analysis and output variable equivalencing, WORK(50) is copied to WORK(108) just prior to calling ANAL9.

If the variable LOOP is set equal to 1, this signifies that data exists in the WORK array, whether from a SAVE file solution or the previous problem. Therefore, the edit option is made available to the user.

Except for the scarf joint, a tension load type requires adhesive peel and adherend transverse properties. When all constraints are input (option = 1), the load type is entered first and is used to determine if prompting is required for the above properties. If option 2 is used to edit existing data, the current values are displayed before allowing editing; therefore, it is necessary to request the load type prior to displaying the values, so those properties may be omitted or included on the screen.

The routine displays the appropriate heading, analysis name, and picture on the screen.

If WORK already contains input data for editing (LOOP = 1), then the routine skips forward to display all the current parameters on the screen.

If all the constraints, or parameters, are to be input (LOOP = 0), then the routine displays and requests values for the three basic joint constraints. Then all the required adhesive properties are displayed and values requested for each by moving the screen cursor under the VALUE heading for each constraint. When complete, the process is repeated for the adherend properties, and LOOP is set equal to 1.

At this point, all required input values have been read into WORK. Boxes are drawn beside each constraint and the RETURN, EXECUTE, and RE-DISPLAY options are displayed. A screen coordinate is requested to modify a constraint or process one of the above options. If an edit box is selected, the screen cursor is moved under the MOD. column for that constraint, allowing the key-in of a modified value. This cycle of requesting a coordinate, selecting a small box, and entering a modified value is continued until the user selects one of the bottom option boxes.

If the user selects RE-DISPLAY, default values are set, the screen is cleared and re-displayed with current values. The boxes are displayed and screen coordinate requested.

RETURN branches the user back to the analysis options immediately.

EXECUTE sets allowed values to their defaults, clears the page and, for the scarf joint, calls ANAL9. For the other analyses, overlay restrictions required returning to DESIGN to call ANAL7; upon returning from ANAL7, BOND1 is re-entered with IA = 1 to branch to where it left for calling the output routine for displaying the solution.

If re-analysis is picked in SELECT, the page is cleared, and the program branches back to call EDSEL.

2. Argument List - none

3. Common - blank, BLK1, IANAL, WORK

4. Length - 2455 Octal

5. Subroutines Called - ANAL9, BOX, BOXNO, EDSEL, NAME, OUT7, OUT9, SELECT, XYLOC

6. Subroutines Called By - DESIGN

7. I/Ø - Read from unit 5 all required input data; write to unit 6 all input data values and problem headings.

8. Error Handling - If an invalid option, number of bond surfaces, or load type is entered, re-entry is requested.

9. Flow Diagram - see Figure 11.

10. Symbol List - The following symbols are not covered by the general list and description.

DIS	- length of picture overlap
IDEL	- delta screen width for square boxes
IDELY	- delta Y screen value for placing cursor IDELY down from JBOXTP coordinate
II	- return code from SELECT
IT	- return code from EDSEL
IX	- X screen coord.
IXX	- X screen coord. for MOD. cursor
IX1	- X screen coord. for left side VALUE cursor
IX2	- X screen coord. for right side VALUE cursor
IY	- Y screen coord.
IYY	- Y screen coord. for MOD. cursor
I1	- starting box number for draws
JBOXTP	- array of Y coord. for top of small edit boxes
K	- load type
KK	- temporary values for new load type
K1	- X value for left side of left box
K2	- X value for right side of left box
LOOP	- set equal to 1 of WORK is full of input data
N,N2	- number of boxes for DO parameter
SYM	- number of bond surfaces for scarf joint
TH1,TH2	- picture display thicknesses; outer, inner

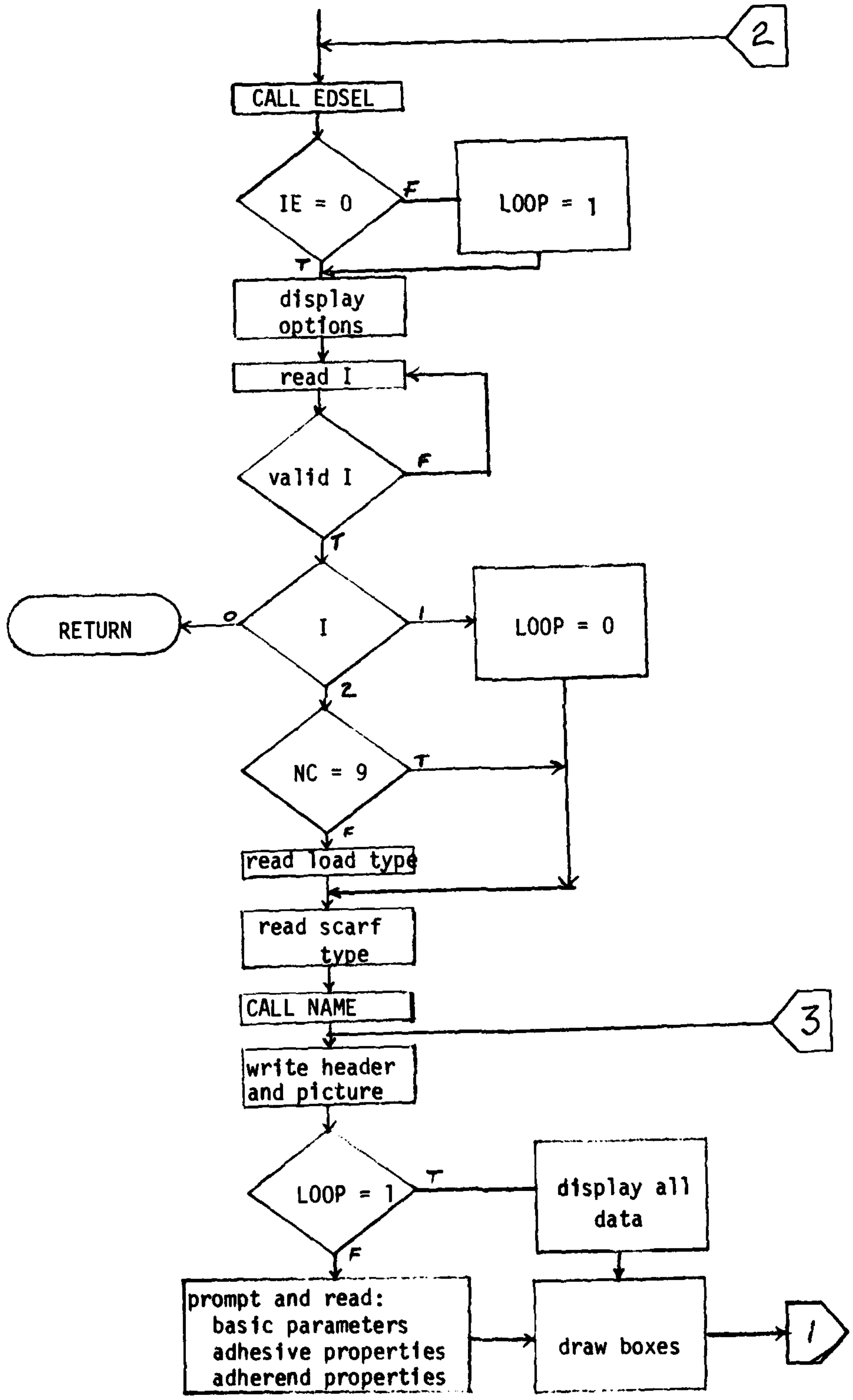


Figure 11. BOND1 flow diagram

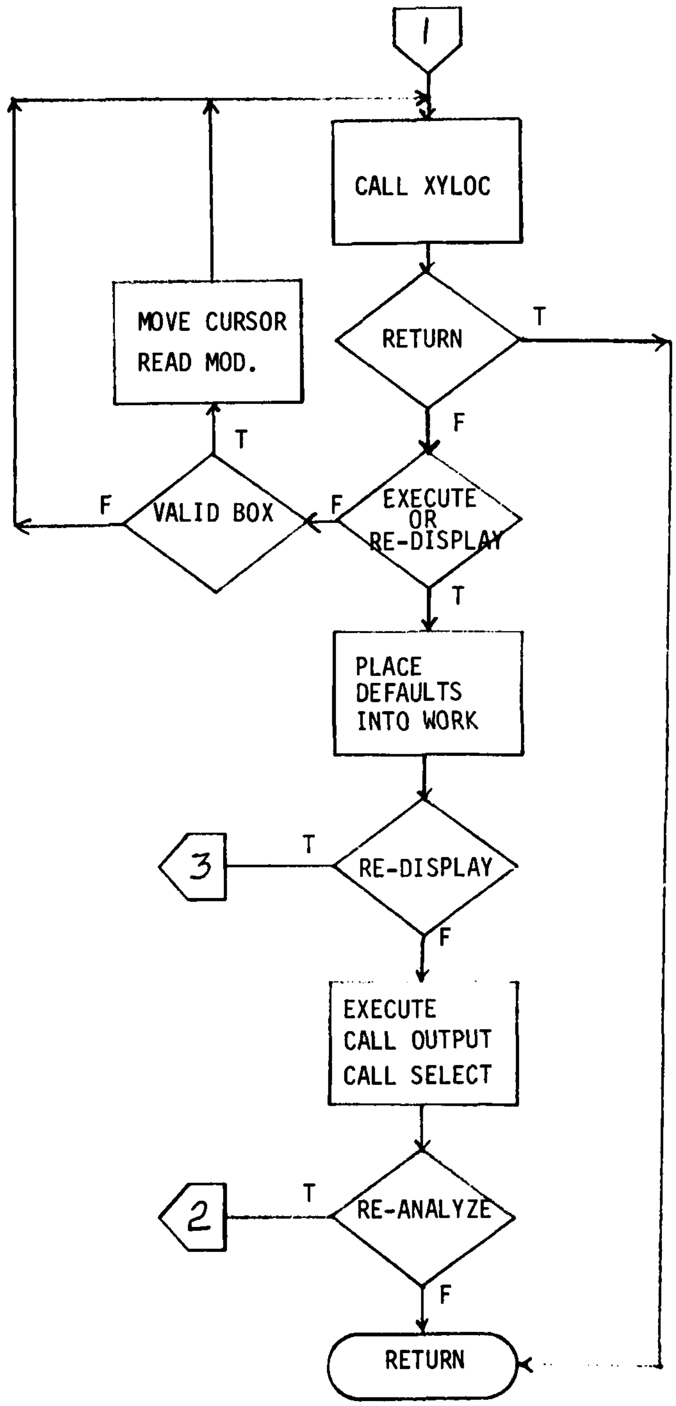


Figure 11. BOND1 Flow Diagram (continued)

BOND2

1. Algorithm - This routine is the interface to the bonded unsupported single-lap joint analysis.

The routine is basically similar to BOND1, except the differences were such that modifying BOND1 would not be as efficient as creating a new overlay program.

Since the BOND1 and BOND2 routines function so closely the same, this routine will cover only the differences.

There is no need to request a type, since only a tension load is analyzed, and the number of parameters required is constant.

The only additional property required is the adherend laminating factor. The temperature properties for the adhesive and the adherend thermal coefficients are not required for the analysis. Also, the adherend properties provide for a balanced joint.

2. Argument List - none

3. Common - blank, BLK1, BLK3, WORK

4. Length - 1231 Octal

5. Subroutines Called - ANAL8, BOX, BOXNO, EDSEL, NAME, OUT8, SELECT, XYLOC

6. Subroutines Called By - DESIGN

7. I/Ø - same as BOND1

8. Error Handling - If an invalid option is keyed in, re-entry is requested. If the problem will not converge, ANAL8 displays a message, and returns NOCONV = 1. The program branches back and requests an option.

9. Flow Diagram - see Figure 12.

10. Symbol List - Refer to the general variable list and BOND1 except for the following:

IYLINI	- Y screen coord. of top line
12	- No. of boxes in column
K3	- X screen coord. of left side of right box
K4	- X screen coord. of right side of right box
NOCONV /BLK3/	- flag that solution will not converge

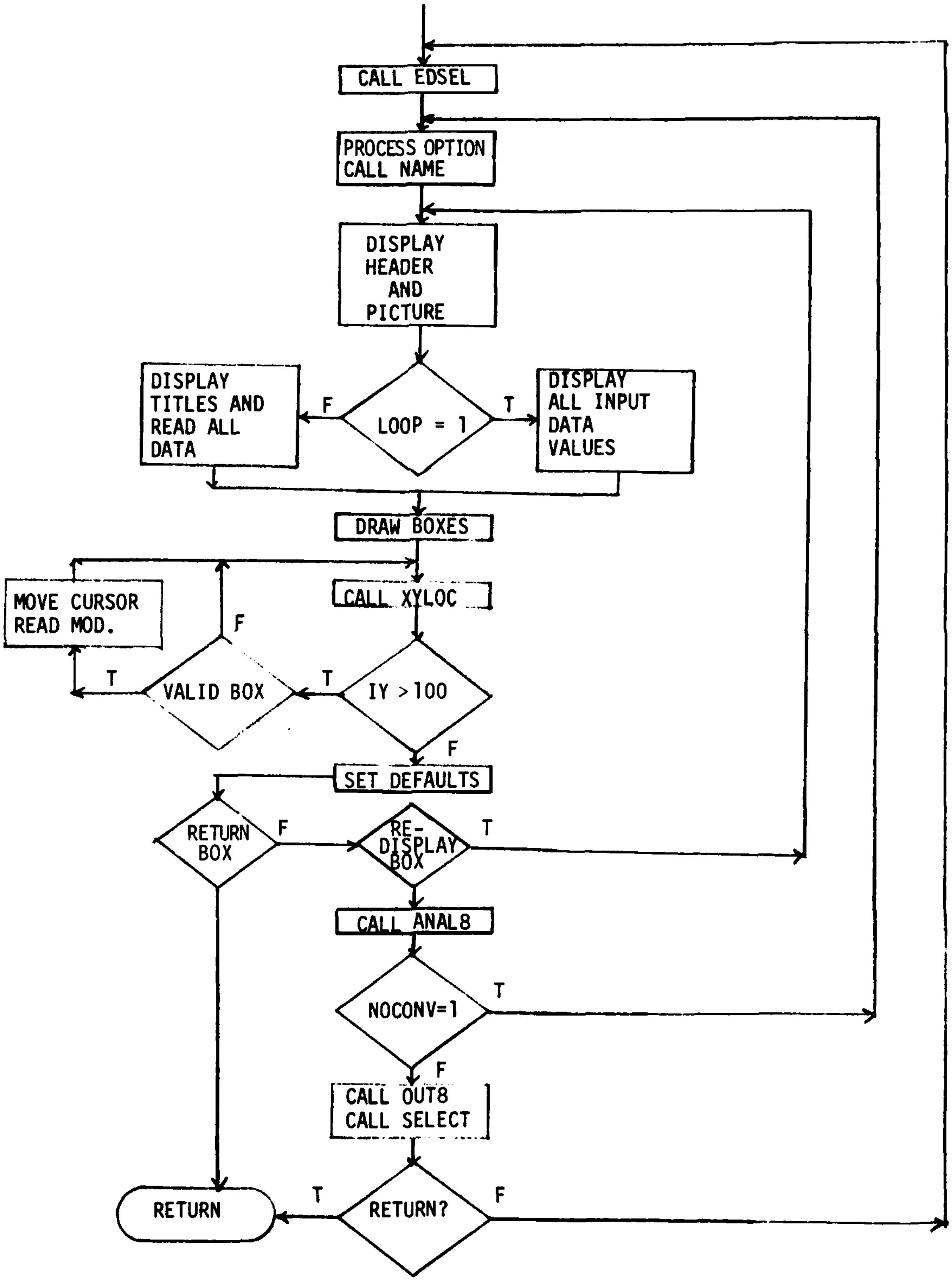


Figure 12. BOND2 Flow Diagram

BOND5

1. Algorithm - This is the input interface routine for the bonded stepped-lap analysis of joints or doublers. All input data values are equivalenced to either WORK or WK.

This is a routine that inputs the constraints by groups; basic, adhesive, and adherend. If editing is desired, the user must re-enter all the items of the group requested for update. Prior to execution the input data is copied from the temporary WK array to WORK by calling COPYWK.

When execution is selected, the analysis routine is initiated by returning to DESIGN and overlaying BOND5 with ANAL11. After execution BOND5 branches to display the analysis summary.

2. Argument List - none

3. Common - blank, BLK1, IANAL, COPY, WK, WORK

4. Length - 2254 Octal

5. Subroutines Called - COPYWK, EDSEL, INIT, NAME, OPTION, OUT11, SELECT

6. Subroutines Called By - DESIGN

7. I/Ø - Writes on unit 6 the display messages for input requests. Reads from unit 5 the parameters.

8. Error Handling - An error message will be printed if an invalid step number has been entered.

9. Flow Diagram - See Figure 13.

10. Symbol List - The following were not previously described under general program variables, and the bonded stepped-lap WORK array.

A	- actual strength value for stepped lap summary
B	- allowable strength
ID	- IDVGT flag
IDEL	- X
IDUM	- dummy argument
IE	- EDSEL return code
II	- SELECT return code
IP	- start location in WK (computed)
IS	- Y screen step depth
IX	- X screen coord.
IY	- Y screen coord.
I1	- set = 1 for RE-INPUT to skip request for name & JTDBLR
KSTART/COPY/	- starting locations in WORK
N	- No. of steps in WK array output data
NOUT	- counter for KSTART and COPYWK
NS	- temporary storage for old NSTEPS value
R	- ratio of A/B
RIM	- minimum R value for inner material
RØM	- minimum R value for outer material
SI	- minimum inner B value
SØ	- minimum outer B value
TI	- minimum inner A value
TØ	- minimum outer A value

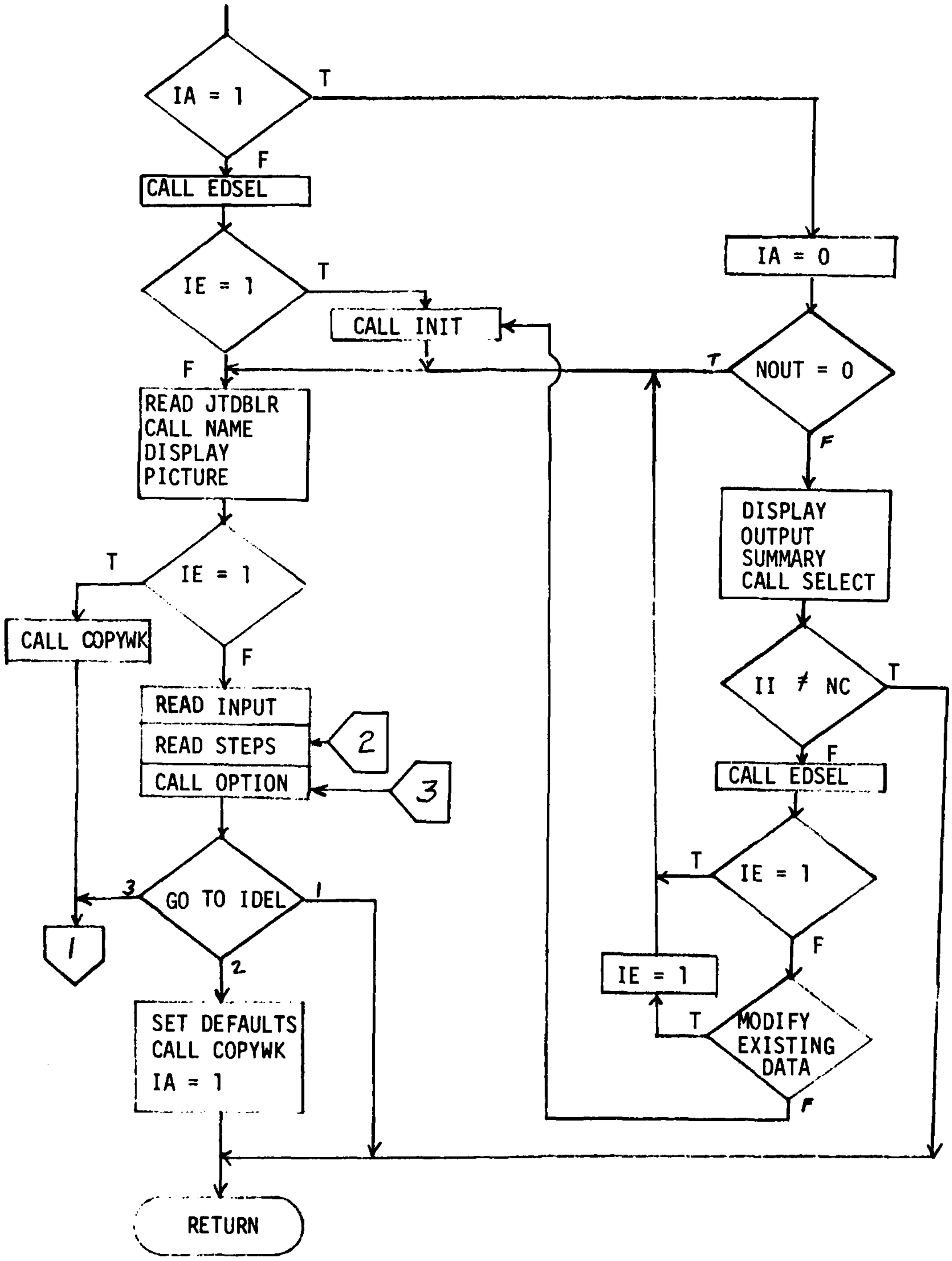


Figure 13. BOND5 Flow Diagram

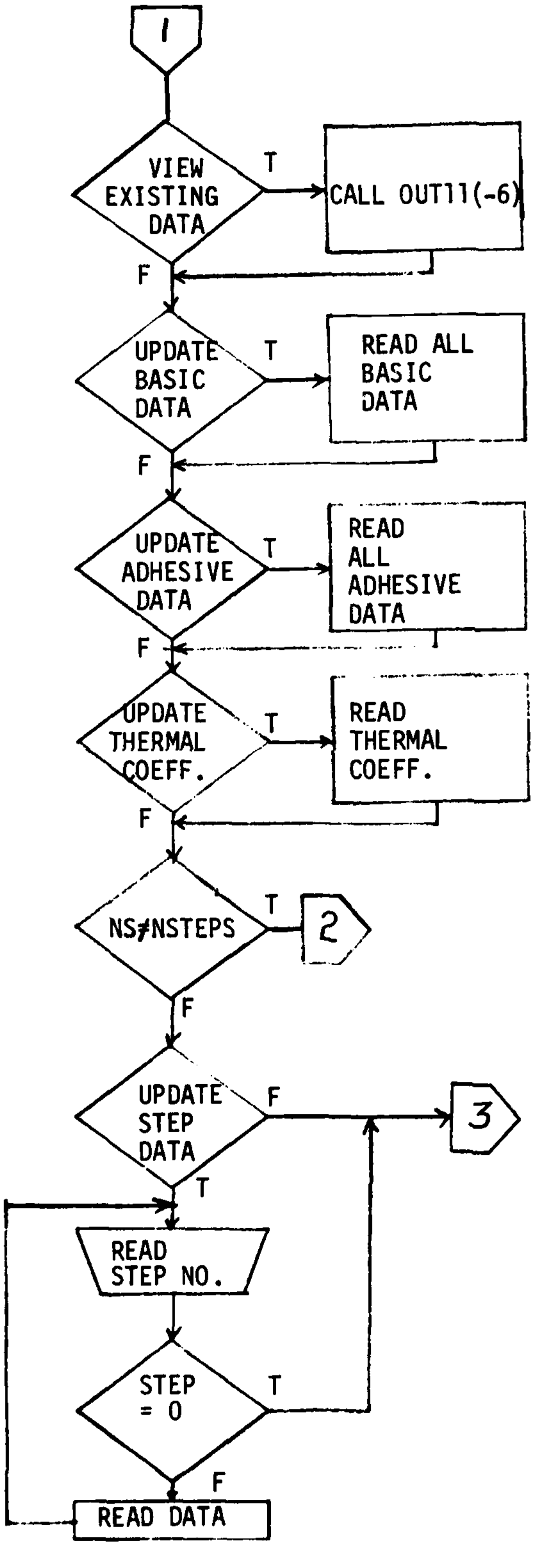


Figure 13. BOND5 Flow Diagram (continued)

BOX

1. Algorithm - This routine draws a square box on the screen given the top left corner coordinates.

2. Argument List - IX, IY, IDEL

3. Common - none

4. Length - 47 Octal

5. Subroutines Called - none

6. Subroutines Called By - BOND1, BOND2

7. I/Ø - draws a box

8. Error Handling - none

9. Flow Diagram - not required

10. Symbol List - none

BOXNO

1. Algorithm - This routine determines the box number detected, if any, for editing. The routine takes the input Y coordinate, N, and returns the box value. If N is returned as zero, the IVAL number does not fall within a box.

2. Argument List - NMAX, ITOP, IDEL, N

3. Common - none

4. Length - 51 Octal

5. Subroutines Called - none

6. Subroutines Called By - BOND1, BOND2

7. I/Ø - none

8. Error Handing - none

9. Flow Diagram - none

10. Symbol List

IDEL	- height of each box
ITP	- array of top coordinates of the boxes
IVAL	- value of N input
IYDIFF	- difference between middle box top and IVAL
N	- input = Y coordinate output = box number
NB	- bottom box number
NMAX	- number of boxes
NMID	- middle box number
NT	- top box number

COPYWK

1. Algorithm - This routine copies items from the WK array into WORK. If J is negative, items are copied from WORK to WK for editing in BOND5.

The KSTART array keeps track of the starting location of the data in WORK.

The WK array contains the data for several arrays; NITEMS indicates the number of arrays in WK for the input value of J. IWS is simply the starting location within WK for each if the items.

The simple method would be to copy all items of WK to WORK, but depending on the number of items in each array, MAX, much space could be wasted on the SAVE file when WORK is copied.

WORK(1) contains a running count of the number of items in the WORK array.

2. Argument List - J, MAX, IDVGT, WK

3. Common - COPY, WORK

4. Length - 145 Octal

5. Subroutines Called - none

6. Subroutines Called By - BOND5, ANAL11

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List:

I	- absolute value of J
IDVGT	- divergent solution flag
IL	- last item in array
IS	- start item in array
IWS	- array of starting locations for WK
J	- flag denoting type of data
K	- loop counter
KSTART	- array of starting locations within WORK
KT	- counter for number of items in WORK
L	- loop counter
MAX	- no. of steps
NI	- no. of items
NITEMS	- array of number of items in IWS array

DBLB

1. Algorithm - Search routine for bolted double-lap joint to determine minimum wt.

2. Argument List - NX, FST, TCMP, MATL, KBOLT, W, D, T, WX, M, PB, PT, LF, FS

3. Common - LBLT

4. Length - 573 Octal

5. Subroutines Called - ANAL, FKBOLT, FPROP, PCT, QUADMN, TH, WDMAX, WDMIN, WT, WTSL, WWT

6. Subroutines Called By - ANAL1

7. I/Ø - none

8. Error Handling - none

9. Flow Chart - none

10. Symbol List - none

DESIGN

1. Algorithm - This routine displays the types of joints available, prompts the user for a selection and branches to the appropriate routine.

2. Argument List - none

3. Common - blank, IANAL, WORK

4. Length - 333 Octal

5. Subroutines Called - OVERLAY

6. Subroutines Called By - MAIN

7. I/Ø - Displays analysis option descriptions and reads option number.

8. Error Handling - Checks for a valid option number

9. Flow Diagram - none

10. Symbol List

    NGO - option number

EDSEL

1. Algorithm - This routine allows the user to select a solution from the SAVE file for editing.

If there are no solutions on the SAVE file with a type the same as the current analysis type, a message stating such is displayed. Otherwise, all the names with a corresponding type are displayed on the screen.

If the user selects RETURN, IT is set equal to zero indicating no solution from the SAVE file was read.

Otherwise, the user selects a name by its screen coordinate. When a valid name has been picked, the screen coordinate is converted to a design number, KN, and the solution is read into WORK.

2. Argument List (IT)

3. Common - blank, BLK1, BLK2, WORK

4. Length - 1001 Octal

5. Subroutines Called - INIT, READ1, XYLOC

6. Subroutines Called By - BOLT4, BOND1, BOND2, BOND5

7. I/Ø - The names of solutions are displayed on the screen.

After the SAVE file has been positioned by READ1, the data is read from file 1.

8. Error Handling - none

9. Flow Diagram - See Figure 14

10. Symbol List - The following variables are not included in the general list:

IT	- set equal to 1 if a name picked
IXMIN	- min. X value of a name on screen
IXP	- array of starting X locations for up to 10 names per row
IYMAX	- max. Y value of a name on screen
IYMIN	- min. Y value of a name on screen computed by 10 names per row
IYP	- array of Y screen coordinates for each row of names
KC	- column no. of name (from 1-10)
KD	- row number of name (from 1-10)
KN	- design number of solution
TNAME	- copy of ANAME with blanks for names with non-corresponding types

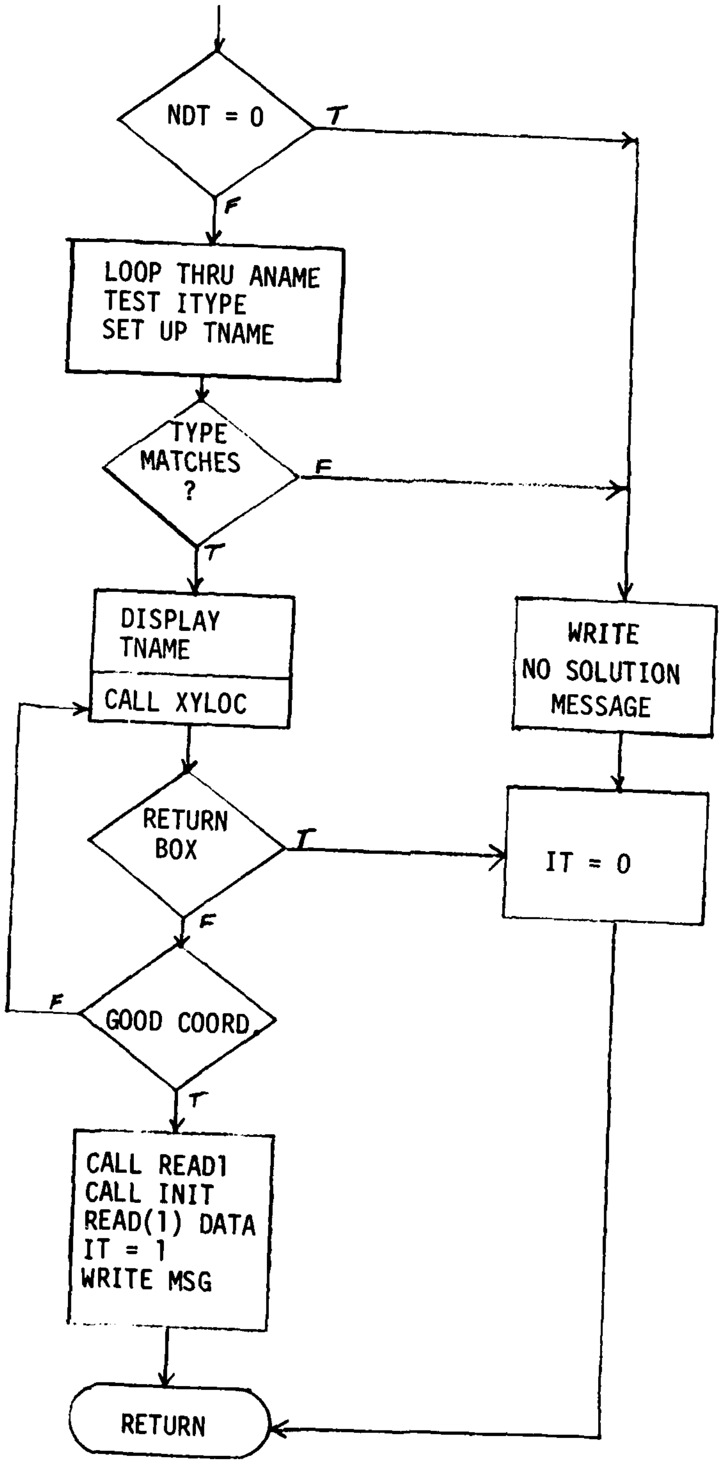


Figure 14. EDSEL Flow Diagram

ESCARF

1. Algorithm - Elastic Analysis of shear in unbalanced scarf joints.

2. Argument List - OL, ETR, THERMA, LCRTND, TAUAVG

3. Common - none

4. Length - 370 Octal

5. Subroutine Called - none

6. Subroutines Called By - ANAL9

7. I/Ø - none

8. Error Handling - Failure cases are flagged by setting TAUAVG = 10000, so as to print asterisks.

9. Flow Diagram - none

10. Symbol List - none

FKBOLT

1. Algorithm - contains properties for bolts.

2. Argument List - KBOLT

3. Common - DBLBLT

4. Length - 50 Octal

5. Subroutines Called - none

6. Subroutines Called By - DBLB, STPLP

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List

    FT - ultimate tensile strength

    FSS - ultimate shear stress

    BK - density factor

    BG - shear modulus

FKPROP

1. Algorithm - Determine the material properties as a function of W and D.

2. Argument List - WD, D

3. Common - DBLBLT

4. Length - 125 Octal

5. Subroutines Called - none

6. Subroutines Called By - DBLB, ANAL, TH, STPLP

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

FPROP

1. Algorithm - Sets up graphite material properties that remain fixed.

2. Argument List - MATL

3. Common - DBLBLT

4. Length - 52 Octal

5. Subroutines Called - none

6. Subroutines Called By - DBLB, ANAL, STPLP

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List:

PROP (1)	=	Ultimate Tensile Strength
PROP (2)	=	Ultimate Bearing Strength
PROP (5)	=	Elastic Modulus
MATL	=	Material Code

INIT

1. Algorithm - Initiatizer WORK array to zero.

2. Argument List - none

3. Common - WORK

4. Length - 6 Octal

5. Subroutine Called - none

7. Subroutined Called By - EDSEL, PRINT, BOLT4, BOND5

6. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

MAIN

1. Algorithm - This is the main routine that initializes data, sets the tablet flag, displays the three main options and branches to the selected routine. Upon EXIT, user messages are displayed.

2. Arguments - none

3. Common - blank, CONSOL, TABFLG, BLK1, BLK2, WK

4. Length - 417 Octal

5. Subroutines Called - OVERLAY (DESIGN, PRINT)

6. Subroutines Called By - none

7. I/Ø = If data exists on SAVE file, the file is read to initialize the ANAME and ITYPE arrays.

   Files 1 and 2 are rewound.

   The main option list is displayed on unit 6 and the option read.

8. Error Handling - An invalid code is re-entered.

   If the user states that data exists on an empty file, reading that file will cause a system read error and abort.

9. Flow Diagram - see Figure 15.

10. Symbol List - The following are not covered by the general list:

    ICODE - main option code entered

    ICON/CONSOL/ - set = 1 if consolidation of SAVE file selected

    ITAB/TABFLG/ - set = 1 if XYLOC routine to use tablet calls

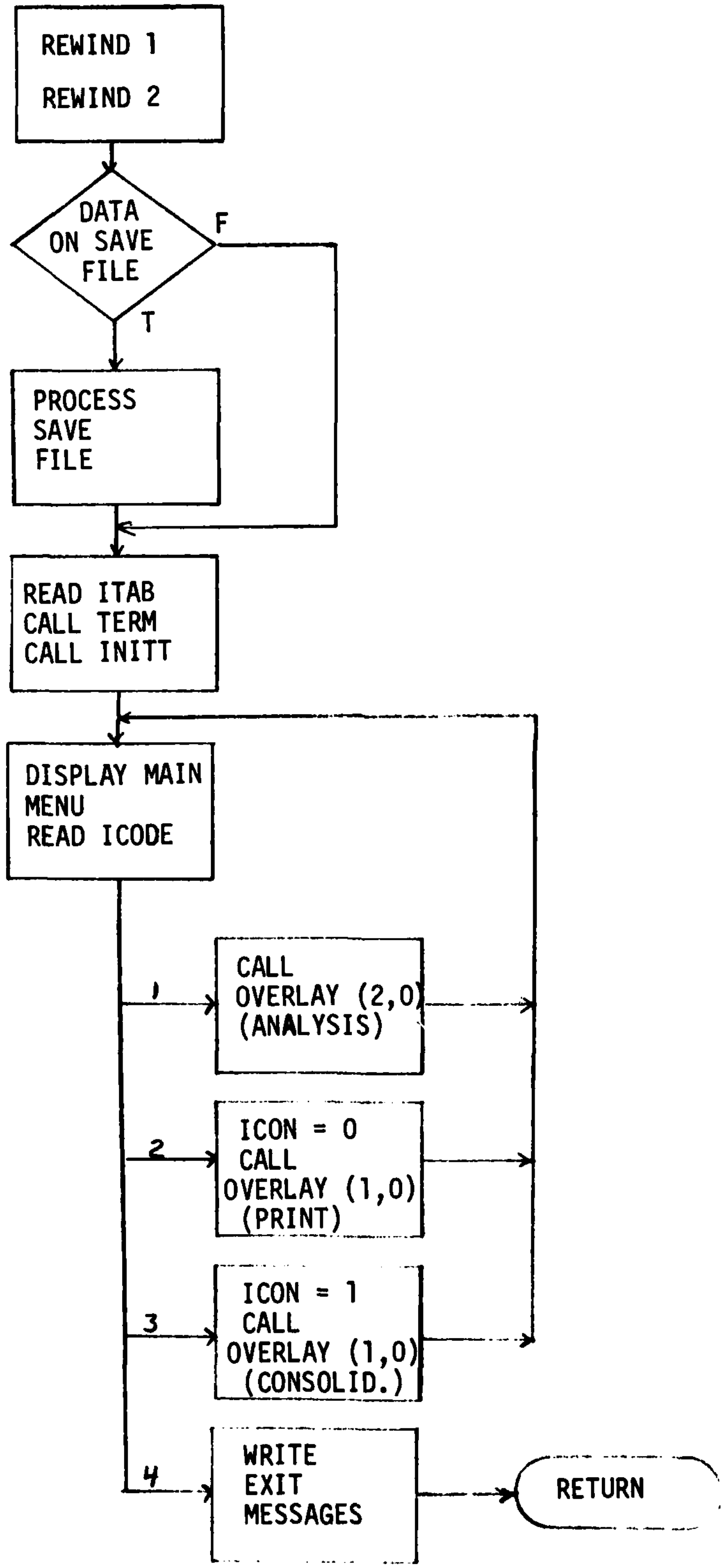


Figure 15. MAIN Flow Diagram

NAME

1. Algorithm - This routine prompts the user for, and reads the name assigned to each analysis problem, and displays elapsed time.

2. Argument List - none

3. Common - BLK1

4. Length - 50 Octal

5. Subroutines Called - none

6. Subroutines Called By - BOLT1, BOLT4, BOND1, BOND2, BOND5

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

OPTION

1. Algorithm - Draws the boxes for RETURN, EXECUTE, and RE-INPUT, requests a screen coorinate, and returns a code of 1, 2 or 3, respectively.

2. Argument List - IX, IY, IDEL

3. Common - none

4. Length - 174 Octal

5. Subroutines Called - XYLOC, BOX

6. Subroutines Called By - BOLT1, BOLT4

7. I/Ø - displays boxes with labels on screen.

8. Error Handling - Keeps requesting a coordinate until one is within a box.

9. Flow Diagram - none

10. Symbol List

IDEL	- delta Y coordinate of box
IDELX	- delta X coordinate from left side of box for labels
IDEL2	- 2 * IDEL; delta X between box top left corners
IR	- return code
IX	- starting X coordinate for first box
IXX	- requested X coordinate
IX1	- starting X coordinate for first label
IX2	- starting X coordinate for second label
IX3	- starting X coordinate for third label
IYY	- starting Y coord. for first box
IY	- requested Y coordinate

OUT1

1. Algorithm - This is the output routine for the bolted double-lap and supported single-lap joints. The input argument is the unit number for the formatted writes.

The type of analysis is dependent on the original parameters MO and NX, as shown.

2. Argument List - NU

3. Common - BLK1, WORK

4. Length - 452 Octal

5. Subroutines Called - none

6. Subroutines Called By - PRINT, BOLT1, SELECT

7. I/Ø - Writes the formatted data onto either the display (Unit 6), or the PRINT file (Unit 2).

8. Error Handling - none

9. Flow Diagram - See Figure 16.

10. Symbol List - The following are not covered by either the general list or the WORK array for these types:

D6	- 6 * D
FAIL	- array of possible failure modes
IPB	- % equivalent of PB decimal array
TYPE	- bolt type array
WD	- W/D

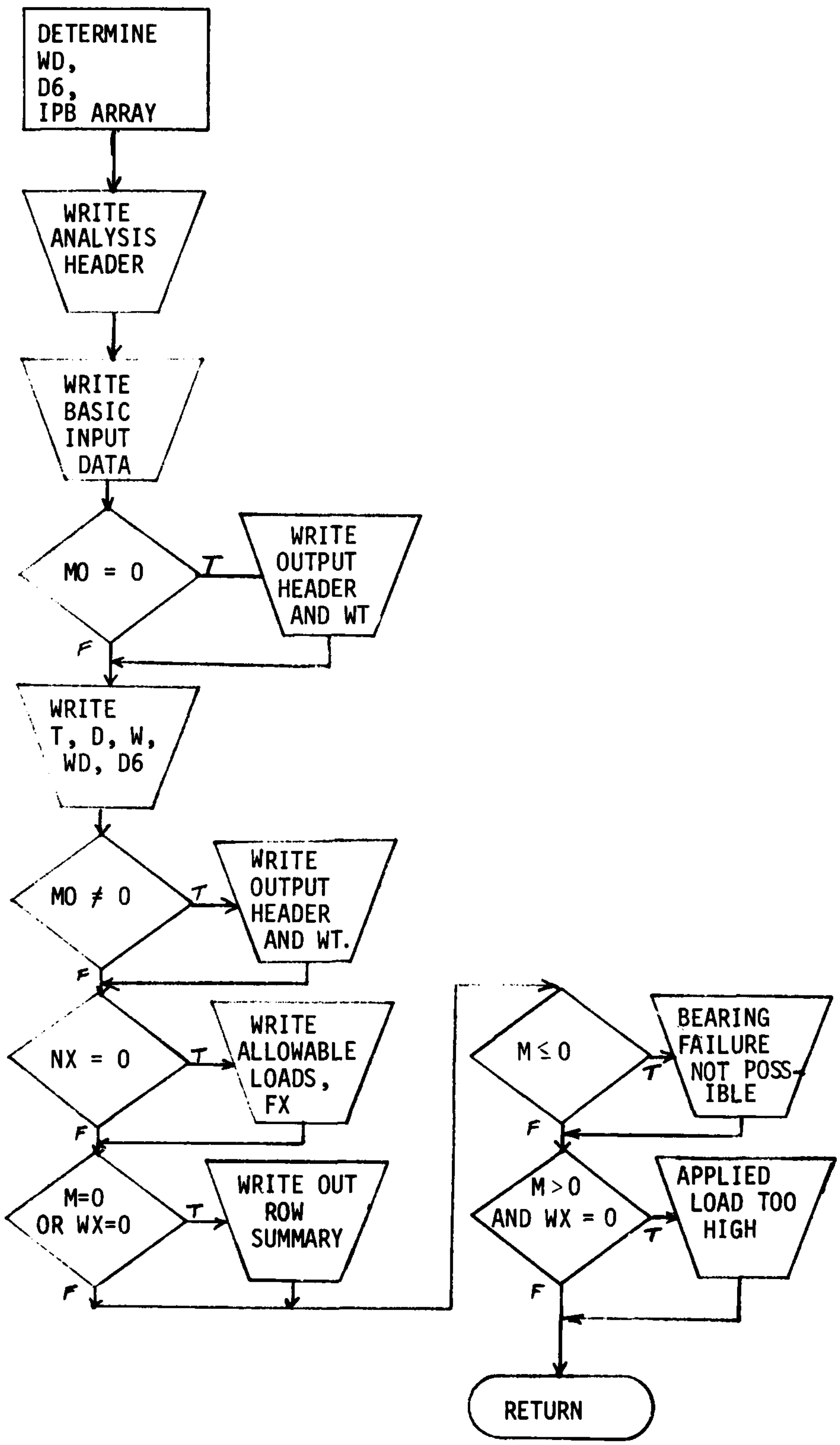


Figure 16. OUT1 Flow Diagram

OUT4

1. Algorithm - Output routine for the bolted stepped-lap joint.

   If NU = -6, the routine has been called to view only existing input data contained in the WORK array.

2. Argument List - NU

3. Common - BLK1, WORK

4. Length - 370 Octal

5. Subroutines Called - none

6. Subroutines Called By - PRINT, BOLT4, SELECT

7. I/Ø - Writes the formatted data to either the display (Unit 6), or the PRINT file (Unit 2).

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - The following are not covered by either the general list or the WORK array for bolted stepped-lap joints.

    BOLT - bolt type array

    FAIL - array of failure modes

    INPUT - flag that only input is to be written

    NU - unit number

OUT7

1. Algorithm - Output routine for solutions of bonded double-lap and supported single-lap joints.

The variable NC selects the appropriate heading, and K the type of load and pertinent properties.

2. Argument List - none

3. Common - blank, BLK1, WORK

4. Length - 676 Octal

5. Subroutines Called - none

6. Subroutines Called By - PRINT, BOND1, SELECT

7. I/Ø - Writes the formatted data to either the display (NU = 6) or the PRINT file (NU = 2).

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - See the appropriate WORK equivalence descriptions.

OUT8

1. Algorithm - Output routine for a bonded unsupported single-lap joint. After writing out the input data, the output formats are dependent on the input overlap length, WORK(2). If zero, seven ℓ/t ratios are used, and each of the data arrays within WORK are written according to their respective formats.

   If WORK(1) $\neq$ 0, strengths are written; if WORK(1) = 0, stresses are written.

2. Argument List - NU

3. Common - BLK1, WORK

4. Length - 525 Octal

5. Subroutines Called - none

6. Subroutines Called By - PRINT, BOND2, SELECT

7. I/Ø - Writes the formatted data to either the display (NU = 6), or PRINT file (NU = 2).

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - Reference the general list for variable descriptions.

OUT9

1. Algorithm - Output routine for bonded scarf joints, symmetrical and asymmetrical.

WORK(1) is the load type (-1,0,+1), and determines the value of K.

WORK(2) determines whether strengths or stresses were computed.

WORK(3) determines whether the specified overlap or a range of 7 overlaps were used.

2. Argument List - NU

3. Common - BLK1, WORK

4. Length - 440 Octal

5. Subroutines Called - none

6. Subroutines Called By - PRINT, BOND1, SELECT

7. I/Ø - Writes the formatted data to either the display (NU = 6), or the PRINT file (NU = 2).

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List:

END	- critical end array (left, right)
K	- load type, IWORK(1) + 2
NUM	- number of items in each array
TYPE	- array of descriptive load types

OUT11

1. Algorithm - Output routine for bonded stepped-lap joints and doublers. If NU is negative, only the input data is to be displayed for the user.

The compressed format and variable length of the arrays within WORK is due to the variable number of steps for the different computations. Reference Table 2. for the typical layout of the WORK array.

IWORK(15) contains number of segments within WORK, from 1 to 4. The first is the input step data, and the others are up to 3 segments of computational output.

2. Argument List - NU

3. Common - BLK1, WORK

4. Length - 626 Octal

5. Subroutines Called - none

6. Subroutines Called By - PRINT, BOND5, SELECT

7. I/Ø = Writes formatted data to either the display (NU = 6), or the PRINT file (NU = 2).

8. Error Handling - none

9. Flow Diagram - Figure 17

10. Symbol List - The following describes the unique variables used. Refer to the general list and the WORK equivalence descriptions for the remainder:

CST	- array of load types
IL	- initial location in each WORK segment
IT	- load type pointer for CST
IUPDAT	- set = 1 if only input to be displayed
KA	- no. of arrays within WORK for previous segment
M	- no. of segments
N	- no. of steps analyzed for each segment

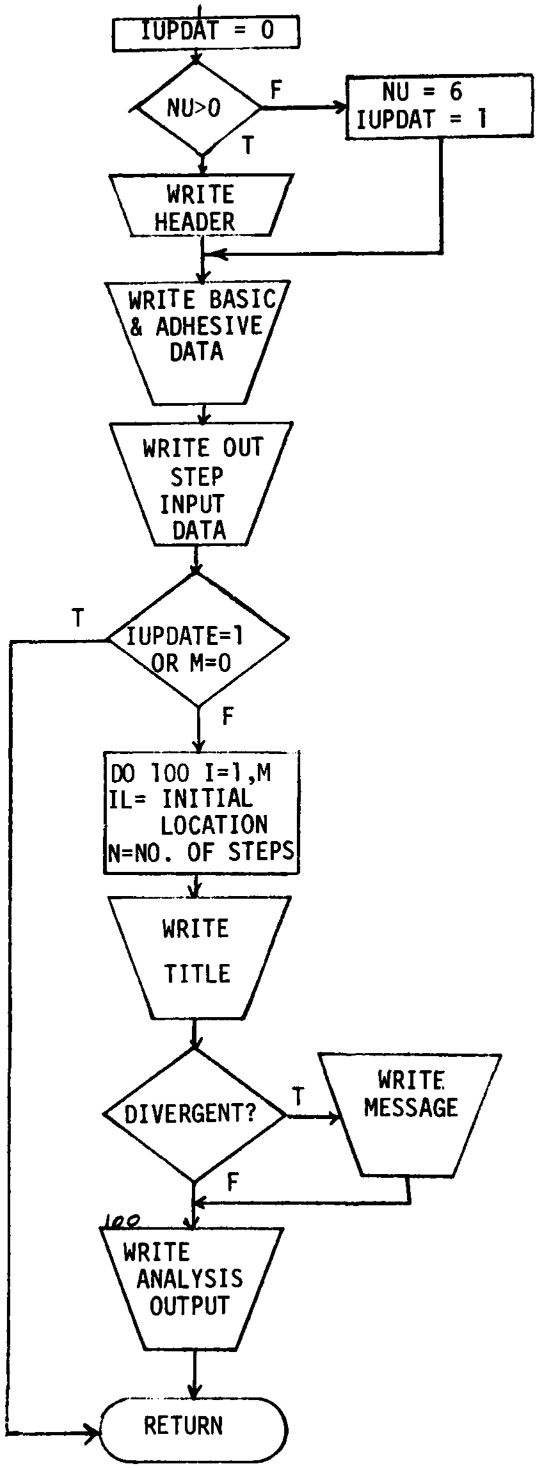


Figure 17. OUT11 Flow Diagram

PCT

1. Algorithm - This routine determines the bolt load distribution for up to 6 rows of bolts of a double-lap joint.

2. Argument List - M, WD, D, T, PB, A

3. Common - DBLBLT

4. Length - 317 Octal

5. Subroutines Called - none

6. Subroutines Called By - DBLB, ANAL, WDMAX, WDMIN, TH

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

PCSTP

1. Algorithm - This routine calculates the amount of load transferred by each row of bolts in a stepped-lap joint.

2. Argument List - EI, EO, G, M, S, D, W, TI, TØ, PCT

3. Common - none

4. Length - 452 Octal

5. Subroutines Called - SID

6. Subroutines Called By - STPLP

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

PRINT

1. Algorithm - This routine, so named because it originally contained only the option to print, also consolidates the SAVE file.

If the user has selected the selective output option (ICON = 0), he is asked whether the solution is to be displayed or output to the PRINT file.

After the appropriate title, all the names on the SAVE file, and option boxes displayed, the user is prompted to pick the names desired by their screen location.

Execution of the print option is accomplished by testing the IPRNT array, locating the solution on the SAVE file, reading the data into WORK, and calling the appropriate output routine. If the solution is displayed, XYLOC is called to interrupt the loop until the user is ready to continue.

Execution of the consolidation option consists of copying all solutions, except those flagged, from the SAVE file to a temporary file (TAPE3) then back to the SAVE file. The design numbers are resequenced in the process.

2. Argument List - none

3. Common - blank, BLK1, BLK2, CONSOL, WORK

4. Length - 1251 Octal

5. Subroutines Called - INIT, OUT1, OUT4, OUT7, OUT8, OUT9, OUT11, READ1, XYLOC

6. Subroutine Called By - MAIN

7. I/Ø - Units 5 and 6 are used to read and display data. For the consolidation option, the selected contents of Unit 1 are copies to Unit 3; Unit 3 is then copied back to Unit 1, to complete consolidation of the SAVE file.

8. Error Handling - If EXECUTE has been selected without any names picked, the user is requested to make another coordinate selection.

9. Flow Diagram - Figure 18

10. Symbol List:

IPRNT	- array for flagged solutions
IT	- solution type
IXMIN	- min. X coord. of a name on screen
IXP	- array of starting X locations for screen names
IYMAX	- max. (top) Y coordinate for name detects
IYMIN	- min. (bottom) Y coordinate for name detects
IYP	- array of Y coordinate for up to 10 rows of names
KC	- column number of selected name (from 1-10)
KD	- row number of selected name (from 1-10)
KN	- design number selected (10*KD+KC)
KNEW	- counter for NDT during consolidation
KOUT	- output response for display
LOOP	- flag for consolidation
NA	- colsolidation read unit
NB	- consolidation write unit
NU	- print unit number

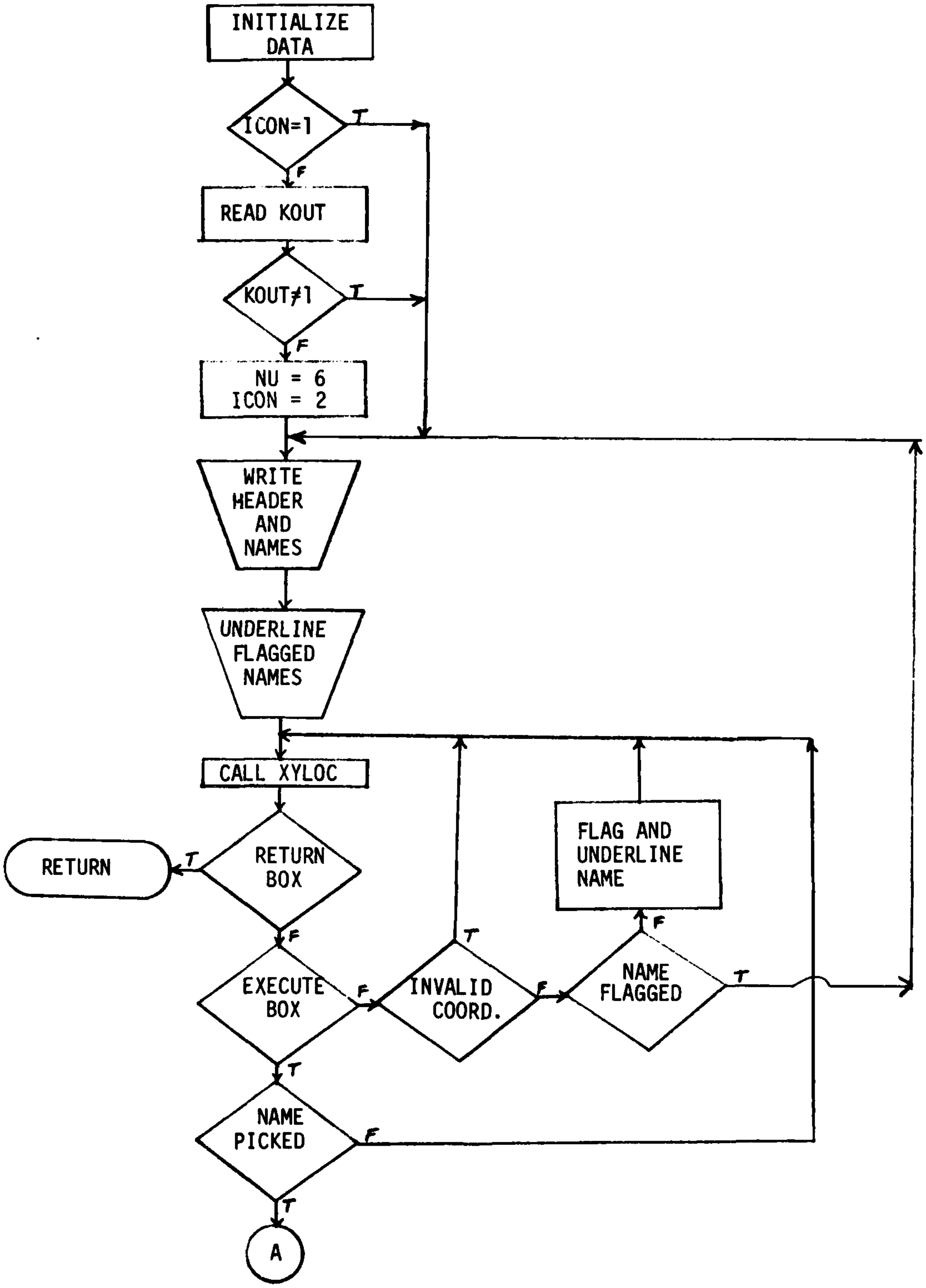


Figure 18. PRINT Flow Diagram

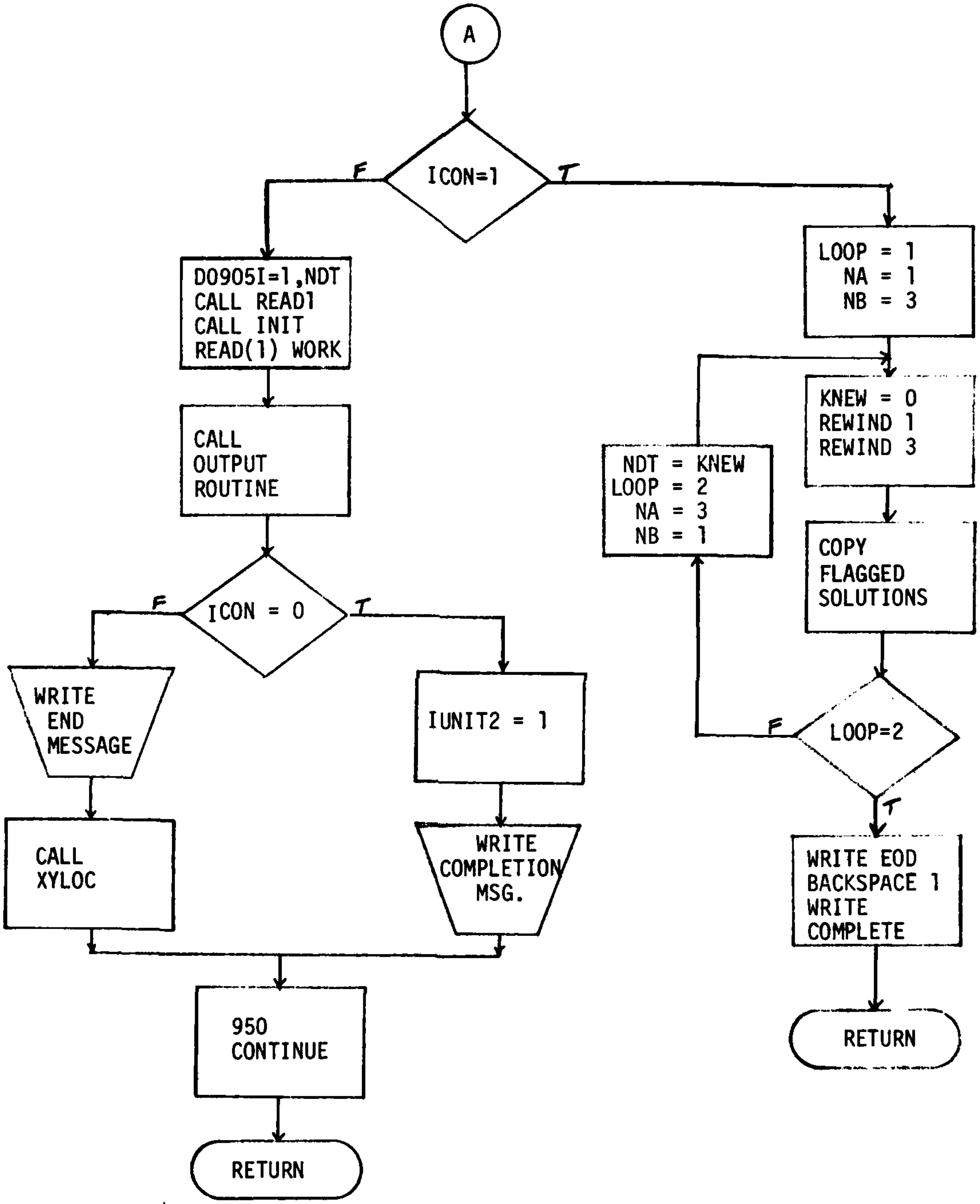


Figure 18 PRINT Flow Diagram (continued)

PSCARF

1. Algorithm - This routine is for the elastic-plastic analysis of unbalanced scarf joints.

2. Argument List - OL, ETR, THERMC, GAMMAR, LCRTND, TAUAVG

3. Common - none

4. Length - 1105 Octal

5. Subroutines Called - none

6. Subroutines Called By - ANAL9

7. I/Ø - none

8. Error Handling - If TAUAVG > 1, there is an error; TAUAVG is set equal to 1000 as a flag and control returned to the calling routine.

9. Flow Diagram - none

10. Symbol List - none

QUADMN

1. Algorithm - This routine finds the X associated with the minimum f(x) by quadratic interpolation.

2. Argument List - X, F, DX, XMAX, DDX, IERR

3. Common - none

4. Length - 525 Octal

5. Subroutines Called - none

6. Subroutines Called By - DBLB

7. I/Ø - none

8. Error Handling - The following error codes may be returned by IERR.

   0 = no error

   1 = $X0 \geq (XMAX-DX)$ and $DF0 \geq 0$.

   2 = $X0 \geq XMAX$

   3 = iterations exceeded 200 max.

9. Flow Diagram - none

10. Symbol List - none

READ1

1. Algorithm - This routine searches the SAVE file for the requested design number. If greater than 100, the file is read to the end of data. If less than 100, the routine locates the solution, reads the name and type, and returns.

2. Argument List - IDES

3. Common - blank, BLK1, BLK2

4. Length - 70 Octal

5. Subroutines Called - none

6. Subroutines Called By - EDSEL, SAVE, PRINT

7. I/Ø - Reads Unit 1 for desired design number.

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List:

    IDES - requested analysis design number

    KD - design number read from SAVE file

    KT - design type read from SAVE file

    TEMP - design name read from SAVE file.

SAVE

1. Algorithm - When a solution is selected for saving on the SAVE file (Unit 1), this routine is called . It only allows 100 solutions to be output. After writing the WORK array data to the SAVE file, the end-of-data record is written and a backspace done to force a buffer dump, and position the file for the next save.

2. Argument List - IT, NENT

3. Common - blank, BLK1, BLK2, WORK

4. Length - 142 Octal

5. Subroutines Called - READ1

6. Subroutines Called By - SELECT

7. I/Ø - Writes 2 records to the SAVE file containing the design number, analysis name, analysis type, and the work array entries. A third record is then written containing the end-of-data flag.

8. Error Handling - If the number of solutions equals 100, a message is displayed that the save was aborted due to max. solutions.

9. Flow Diagram - none

10. Symbol List - none

SELECT

1. Algorithm - This routine processes the user options after display of an executed analysis.

The options to PRINT, SAVE, re-analyze, and return are displayed on a line, separated by asterisks. The user is requested to make selections by the horizontal screen location picked. The PRINT and SAVE options must be processed before a re-analysis or return option for obvious reasons. When either of the first two options is processed, a flag is set to prevent repeating that selection inadvertently.

If RETURN is selected, the value of N is returned as zero to the calling routine.

2. Argument List - N, NENT

3. Common - unlabeled

4. Length - 174 Octal

5. Subroutines Called - OUT1, OUT11, OUT4, OUT7, OUT8, OUT9, SAVE, XYLOC

6. Subroutines Called By - BOLT1, BOLT4, BOND1, BOND2, BOND5

7. I/Ø - display of options

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List

    IP - set = 1 after PRINT selection

    IS - set = 1 after SAVE selection

    N - Input = analysis type
    Output = return code (0 = RETURN)

SID

1. Algorithm - A single-precision simultaneous equation solver, inverse finder, and determinent routine.

2. Argument List - A, N, NDROW, NDCOLA, B, M, NDCOLB, SIGDIG, IERROR, PIVOT, INDEX, SCALEB

3. Common - none

4. Length - 607 Octal

5. Subroutines Called - none

6. Subroutines Called By - PCTSTP

7. I/Ø - none

8. Error Handling - IERROR returned to calling routine

9. Flow Diagram - none

10. Symbol List - none

STPLP

1. Algorithm - Bolted stepped-lap joint analysis routine to determine the amount of load retained by the inner and outer adherends, and determine the margin of safety and failure mode.

2. Argument List - none

3. Common - WORK, BLOCK

4. Length - 377 Octal

5. Subroutines Called - FKPROP, FKBOLT, FPROP, PCTSTP

6. Subroutines Called By - BOLT4

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

TH

1. Algorithm - Function subprogram for determining the joint thickness of double-lap bolted joint.

2. Argument List - NX, M, WD, D

3. Common - DBLBLT

4. Length - 340 Octal

5. Subroutines Called - FKPROP, PCT

6. Subroutines Called By - DBLB, WDMAX, WDMIN, WWT

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

WDMAX

1. Algorithm - Determines a maximum W/D ratio for a bolted double-lap joint.

2. Argument List - NX, M, WD, D

3. Common - DBLBLT

4. Length - 243 Octal

5. Subroutines Called - PCT, TH

6. Subroutines Called By - DBLB

7. I/Ø - None

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

WDMIN

1. Algorithm - Determines a minimum W/D ratio for a bolted double-lap joint.

2. Argument List - NX, M, WD, D

3. Common - DBLBLT

4. Length - 265 Octal

5. Subroutines Called - PCT, TH

6. Subroutines Called By - DBLB

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

WT

1. Algorithm - Function subprogram that determines the weight penalty for a double-lap bolted splice.

2. Argument List - X

3. Common - DBLBLT

4. Length - 66 Octal

5. Subroutines Called - none

6. Subroutines Called By - DBLB

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

WTSL

1. Algorithm - Determines the weight penalties for single-lap bolted splice.

2. Argument List - X

3. Common - DBLBLT

4. Length - 44 Octal

5. Subroutines Called - none

6. Subroutines Called By - DBLB, WWT

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

WWT

1. Algorithm - A function that sets up the X array for determining the weight penalty of a bolted splice.

2. Argument List - WD

3. Common - DBLBLT

4. Length - 43 Octal

5. Subroutines Called - WT, TH, WTSL

6. Subroutines Called By - DBLB

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List - none

XYLOC

1. Algorithm - This routine calls PLOT10 routines for screen X & Y coordinates. If ITAB = 0, the routine calls DCURSR for the coordinates. If not, the user is notified that the tablet is on; the routine then loops to track the cursor position on the screen until the pen is depressed on the tablet.

2. Argument List - IX, IY

3. Common - TABFLG

4. Length - 76 Octal

5. Subroutines Called - none

6. Subroutines Called By - SELECT, EDSEL, OPTION, PRINT

7. I/Ø - none

8. Error Handling - none

9. Flow Diagram - none

10. Symbol List -

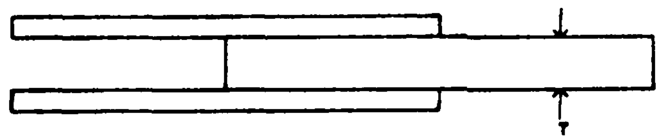
    IC - dummy ASCII character

    IH - ASCII character

    IX - X screen coord.

    IY - Y screen coord.

BOLTED -- STANDARD DOUBLE LAP JOINT
ANALYSIS NAME = BOLT1-9



DESCRIPTION OF INPUT CONSTRAINTS

P = JOINT LOAD (LB./IN.)

FS = JOINT M.S. FACTOR FOR TENSION

TEMP = JOINT TEMP. (DEG. F.)

MATL = % 0-DEGREE GRAPHITE PLIES (25 OR 37)

BOLT = 1 (TITANIUM)
= 2 (STEEL)

N = NO. OF BOLT ROWS

ENTER THE FOLLOWING IF N > 0

T = MATERIAL THICKNESS
D = BOLT DIAMETER
W = WIDTHWISE BOLT SPACING

ENTER VALUES FOR P, FS, TEMP, MATL, BOLT, N: 0 1.25 50 25 1 2

ENTER VALUES FOR T, D, W: .3 .25 2

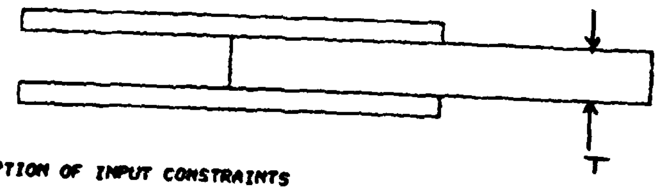
RETURN | EXECUTE | RE-INPUT

Figure 19. Bolted Double-Lap Input (Analysis)

```
        BALANCED BOLTED DOUBLE-LAP COMPOSITE JOINT ANALYSIS PRINTOUT
                        ANALYSIS NAME - BOLT1-9

CODE      INPUT DATA:                              VALUE

NX          JOINT LOAD  (LB./IN.)                    0.
FS          JOINT M.S. TENSION FACTOR             1.25
TEMP        JOINT TEMP  (DEG. F.)                   50.
MATL        % 0-DEGREE GRAPHITE PLIES               25
BOLT        BOLT TYPE                          1 (TITANIUM)
N           NO. OF BOLT ROWS                         2

T           MATL  THICKNESS   (IN.)               .300
D           BOLT DIAMETER     (IN.)               .250
W           BOLT SPACING      (IN.)              2.000
            W/D RATIO                            8.000
            6-D ROW SPACING                      1.500


          OUTPUT DATA:

            JOINT WEIGHT    (LB/IN)              .0858
            MAX. JOINT LOAD (LB/IN)              4879.

              SUMMARY OF BOLT ROW STRENGTHS

          BOLT    % OF LOAD    MARGIN OF    FAILURE
          ROW    TRANSFERRED    SAFETY       MODE

           1         50            .43      TENSION
           2         50           0.00      TENSION

*  CUTPUT TO PRINT FILE *   OUTPUT TO SAVE FILE   *  RE-ANALYZE  *  RETURN  *

                          (COMPLETE)



  3.236 CP SECONDS ELAPSED.
ENTER ANALYSIS NAME: bolt1-11
```

Figure 20. Bolted Double-Lap Output (Analysis)

BOLTED -- STANDARD DOUBLE LAP JOINT
ANALYSIS NAME = BOLT1-11



DESCRIPTION OF INPUT CONSTRAINTS

P = JOINT MEMBRANE LOAD (LBS/IN)

FS = JOINT M.S. FACTOR FOR TENSION

TEMP = JOINT TEMP. (DEG. F.)

MATL = % 0-DEGREE GRAPHITE PLIES (25 OR 37)

BOLT = 1 (TITANIUM)

= 2 (STEEL)

N = NO. OF BOLT ROWS

ENTER THE FOLLOWING IF N > 0

T = MATERIAL THICKNESS
D = BOLT DIAMETER
W = WIDTHWISE BOLT SPACING

ENTER VALUES FOR P, FS, TEMP, MATL, BOLT, N: 14000 1.2 0 37 2 0

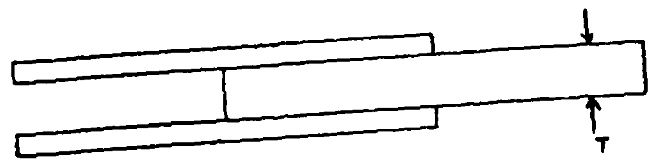
RETURN   EXECUTE   RE-INPUT

Figure 21. Bolted Double-Lap Input (Optimization)

```
          BALANCED BOLTED DOUBLE-LAP COMPOSITE JOINT ANALYSIS PRINTOUT
                          ANALYSIS NAME = BOLT1-11

 CODE     INPUT DATA:                            VALUE

 NX         JOINT LOAD  (LB./IN.)               14000.
 FS         JOINT R.S. TENSION FACTOR             1.20
 TEMP       JOINT TEMP  (DEG. F.)                   0.
 MATL       % 0-DEGREE GRAPHITE PLIES               37
 BOLT       BOLT TYPE                          2 (STEEL)
 N          NO. OF BOLT ROWS                         1

 T          MATL  THICKNESS   (IN.)               .654
 D          BOLT DIAMETER     (IN.)               .688
 W          BOLT SPACING      (IN.)              2.283
            W/D RATIO                            3.321
            6-D ROW SPACING                      4.125


          OUTPUT DATA:

            JOINT WEIGHT     (LB/IN)             .3707

               SUMMARY OF BOLT ROW STRENGTHS

          BOLT    % OF LOAD      MARGIN OF     FAILURE
          ROW     TRANSFERRED     SAFETY        MODE

           1        100            -.00        TENSION
NO JOINT DESIGN BASED ON BEARING FAILURE IS POSSIBLE

% OUTPUT TO PRINT FILE %  OUTPUT TO SAVE FILE   %  RE-ANALYZE  %  RETURN  %



 13.126 CP SECONDS ELAPSED.
ENTER ANALYSIS NAME: bolt1-12
```

Figure 22.   Bolted Double-Lap Output (Optimization)

BOLTED -- STANDARD DOUBLE LAP JOINT
ANALYSIS NAME = BOLT1-12



DESCRIPTION OF INPUT CONSTRAINTS

P = JOINT MEMBRANE LOAD (LBS/IN)

FS = JOINT M.S. FACTOR FOR TENSION

TEMP = JOINT TEMP. (DEG. F.)

MATL = % 0-DEGREE GRAPHITE PLIES (25 OR 37)

BOLT = 1 (TITANIUM)

= 2 (STEEL)

N = NO. OF BOLT ROWS

ENTER THE FOLLOWING IF N > 0

T = MATERIAL THICKNESS
D = BOLT DIAMETER
W = WIDTHWISE BOLT SPACING

ENTER VALUES FOR P, FS, TEMP, MATL, BOLT, N: 0 1.2 0 37 2 1

ENTER VALUES FOR T, D, W: .654 .688 2.283

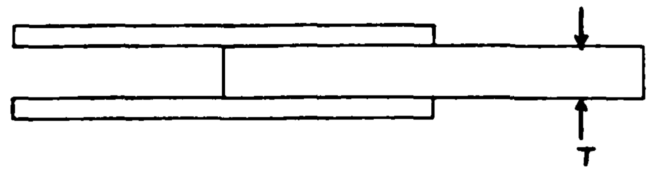
RETURN | EXECUTE | RE-INPUT

Figure 23. Bolted Double-Lap Input

```
        BALANCED BOLTED DOUBLE-LAP COMPOSITE JOINT ANALYSIS PRINTOUT
                      ANALYSIS NAME - BOLT1-12

CODE     INPUT DATA:                                VALUE

NX          JOINT LOAD  (LB./IN.)                    0.
FS          JOINT M.S. TENSION FACTOR              1.20
TEMP        JOINT TEMP  (DEG. F.)                    0.
MATL        % 0-DEGREE GRAPHITE PLIES               37
BOLT        BOLT TYPE                            2 (STEEL)
N           NO. OF BOLT ROWS                         1

T           MATL  THICKNESS  (IN.)                .654
D           BOLT DIAMETER    (IN.)                .688
W           BOLT SPACING     (IN.)               2.283
            W/D RATIO                            3.318
            G-D ROW SPACING                      4.128

         OUTPUT DATA:

            JOINT WEIGHT     (LB/IN)             .3712
            MAX. JOINT LOAD (LB/IN)             14004.

                SUMMARY OF BOLT ROW STRENGTHS

         BOLT    % OF LOAD     MARGIN OF    FAILURE
         ROW    TRANSFERRED     SAFETY       MODE

          1        100           0.00       TENSION

NO JOINT DESIGN BASED ON BEARING FAILURE IS POSSIBLE

*  OUTPUT TO PRINT FILE *   OUTPUT TO SAVE FILE   *  RE-ANALYZE  *  RETURN  *



 13.206 CP SECONDS ELAPSED.
ENTER ANALYSIS NAME: bolt1-13
```

Figure 24.   Bolted Double-Lap Output

BOLTED -- STANDARD DOUBLE LAP JOINT
ANALYSIS NAME = BOLT1-13



DESCRIPTION OF INPUT CONSTRAINTS

P = JOINT MEMBRANE LOAD (LBS/IN)

FS = JOINT M.S. FACTOR FOR TENSION

TEMP = JOINT TEMP. (DEG. F.)

MATL = % 0-DEGREE GRAPHITE PLIES (25 OR 37)

BOLT = 1 (TITANIUM)

= 2 (STEEL)

N = NO. OF BOLT ROWS

ENTER THE FOLLOWING IF N > 0

T = MATERIAL THICKNESS
D = BOLT DIAMETER
W = WIDTHWISE BOLT SPACING

ENTER VALUES FOR P, FS, TEMP, MATL, BOLT, N: 10000 1 0 25 1 1

ENTER VALUES FOR T, D, W: .5 .75 2

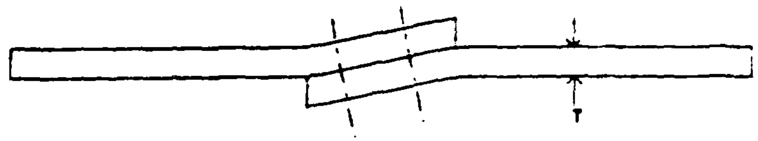
RETURN | EXECUTE | RE-INPUT

Figure 25. Bolted Double-Lap Input (P≠0, N≠0)

```
          BALANCED BOLTED DOUBLE-LAP COMPOSITE JOINT ANALYSIS PRINTOUT
                          ANALYSIS NAME - BOLT1-13

CODE      INPUT DATA:                              VALUE

NX          JOINT LOAD  (LB./IN.)                 10000.
FS          JOINT M.S. TENSION FACTOR              1.00
TEMP        JOINT TEMP  (DEG. F.)                  0.
MATL        % 0-DEGREE GRAPHITE PLIES             25
BOLT        BOLT TYPE                              1 (TITANIUM)
N           NO. OF BOLT ROWS                       1

T           MATL. THICKNESS  (IN.)                 .500
D           BOLT DIAMETER    (IN.)                 .750
W           BOLT SPACING     (IN.)                2.000
            W/D RATIO                             2.667
            G-D ROW SPACING                       4.500

          OUTPUT DATA:

            JOINT WEIGHT    (LB/IN)               .2559

              SUMMARY OF BOLT ROW STRENGTHS

          BOLT    % OF LOAD     MARGIN OF    FAILURE
          ROW     TRANSFERRED    SAFETY       MODE

           1        100            .20       TENSION

NO JOINT DESIGN BASED ON BEARING FAILURE IS POSSIBLE

*  OUTPUT TO PRINT FILE *   OUTPUT TO SAVE FILE   *  RE-ANALYZE  *  RETURN  *
```

Figure 26.   Bolted Double-Lap Output (Margins and Weight)

BOLTED -- UNSUPPORTED SINGLE-LAP JOINT
ANALYSIS NAME = BOLT-2



DESCRIPTION OF INPUT CONSTRAINTS

P - JOINT LOAD (LB./IN.)

FS - JOINT M.S. FACTOR FOR TENSION

TEMP - JOINT TEMP. (DEG. F.)

MATL - % 0-DEGREE GRAPHITE PLIES (25 OR 37)

BOLT = 1 (TITANIUM)
= 2 (STEEL)

N - NO. OF BOLT ROWS

ENTER THE FOLLOWING IF N > 0

T - MATERIAL THICKNESS
B - BOLT DIAMETER
W - WIDTHWISE BOLT SPACING

ENTER VALUES FOR P, FS, TEMP, MATL, BOLT, N: 14000 1 0 25 1 0

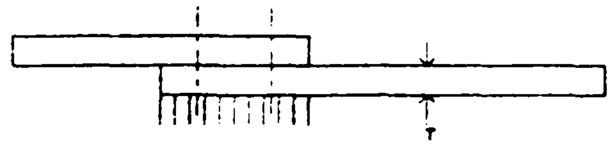
RETURN | EXECUTE | RE-INPUT

Figure 27. Bolted Unsupported Single-Lap Input

```
        BOLTED -- UNSUPPORTED SINGLE-LAP JOINT
                     ANALYSIS NAME - BOLT-2

CODE     INPUT DATA:                          VALUE

P            JOINT LOAD (LB./IN.)            14000.
FS           JOINT M.S. TENSION FACTOR        1.00
TEMP         JOINT TEMP  (DEG. F.)              0.
MATL         % 0-DEGREE GRAPHITE PLIES          25
BOLT         BOLT TYPE                       1 (TITANIUM)
N            NO. OF BOLT ROWS                    2

         OUTPUT DATA:

             JOINT WEIGHT    (LB/IN)         .8450

T            MAT'L THICKNESS  (IN.)          1.264
D            BOLT DIAMETER    (IN.)           .813
W            BOLT SPACING     (IN.)          3.520
             W/D RATIO                       4.333
             6-D ROW SPACING                 4.875

               SUMMARY OF BOLT ROW STRENGTHS

         BOLT    % OF LOAD     MARGIN OF    FAILURE
         ROW     TRANSFERRED    SAFETY       MODE

          1         50            .25       TENSION
          2         50            .00       TENSION

*** BEARING CONTROLLED JOINT DESIGN NOT POSSIBLE ***

*  OUTPUT TO PRINT FILE *   OUTPUT TO SAVE FILE   *  RE-ANALYZE  *  RETURN  *
```

Figure 28. Bolted Unsupported Single-Lap Output

BOLTED -- SUPPORTED SINGLE-LAP JOINT
ANALYSIS NAME = BOLT-3



DESCRIPTION OF INPUT CONSTRAINTS

P = JOINT LOAD (LB./IN.)

FS = JOINT M.S. FACTOR FOR TENSION

TEMP = JOINT TEMP. (DEG. F.)

MATL = % 0-DEGREE GRAPHITE PLIES (25 OR 37)

BOLT = 1 (TITANIUM)
= 2 (STEEL)

N = NO. OF BOLT ROWS

ENTER THE FOLLOWING IF N > 0

T = MATERIAL THICKNESS
D = BOLT DIAMETER
W = WIDTHWISE BOLT SPACING

ENTER VALUES FOR P, FS, TEMP, MATL, BOLT, N: 14000 1 0 37 2 1

ENTER VALUES FOR T, D, W: .687 .75 3.74

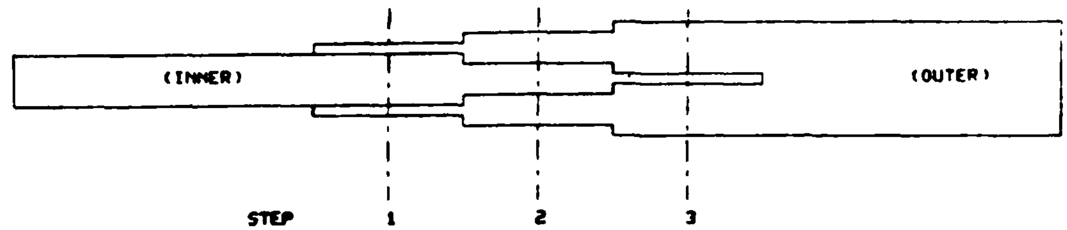
RETURN EXECUTE RE-INPUT

Figure 29. Bolted Supported Single-Lap Input

```
BOLTED -- SUPPORTED SINGLE-LAP JOINT
                    ANALYSIS NAME - BOLT-3

CODE     INPUT DATA:                          VALUE

P           JOINT LOAD (LB./IN.)             14000.
FS          JOINT M.S. TENSION FACTOR          1.00
TEMP        JOINT TEMP  (DEG. F.)              0.
MATL        % 0-DEGREE GRAPHITE PLIES          37
BOLT        BOLT TYPE                         2 (STEEL)
N           NO. OF BOLT ROWS                    1

T           MAT'L THICKNESS   (IN.)           .687
D           BOLT DIAMETER     (IN.)           .750
W           BOLT SPACING      (IN.)          3.740
            W/D RATIO                        4.987
            6-D ROW SPACING                  4.500


         OUTPUT DATA:

            JOINT WEIGHT     (LB/IN)        .2836

              SUMMARY OF BOLT ROW STRENGTHS

         BOLT    % OF LOAD     MARGIN OF    FAILURE
         ROW     TRANSFERRED    SAFETY       MODE

          1        100           -.16       TENSION

* OUTPUT TO PRINT FILE *   OUTPUT TO SAVE FILE   * RE-ANALYZE * RETURN *




      (COMPLETE)
```

Figure 30. Bolted Supported Single-Lap Output

BOLTED -- STEPPED-LAP JOINT ANALYSIS
ANALYSIS NAME = BOLT4-14




```
---> BASIC INPUT DATA:

        1) NO. OF BOLT ROWS (STEPS)
        2) JOINT LOAD (LB./IN.)
        3) JOINT TEMP (DEG. F.)
        4) JOINT TENSION FACTOR
        5) BOLT MATERIAL (1=TITANIUM, 2=STEEL)
        6) % 0-DEGREE PLIES OF INNER GRAPHITE PATTERN (25 OR 37)
        7) % 0-DEGREE PLIES OF OUTER GRAPHITE PATTERN (25 OR 37)

---> BOLT ROW DATA:

        L  = STEP LENGTH (LAND)
        D  = BOLT DIAMETER
        SP = BOLT SPACING
        TI = INNER MATERIAL THICKNESS
        TO = OUTER MATERIAL THICKNESS

ENTER 7 BASIC DATA VALUES: 3 20000 30 1.25 1 25 37

ENTER L, D, SP, TI, TO FOR EACH STEP.

STEP  1 : 2 .375 2.5 .4 .2

STEP  2 : 2 .25  3   .3 .4

STEP  3 : 2 .375 2.5 .2 .8
```

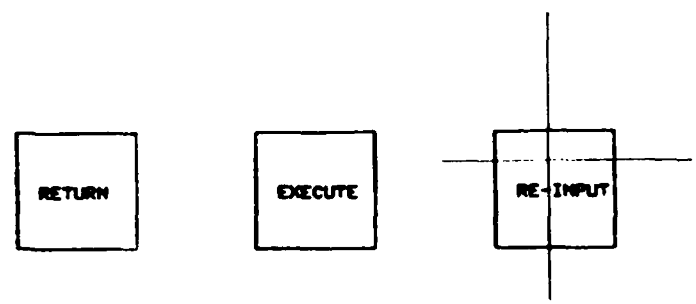


Figure 31. Bolted Stepped-Lap Input

```
VIEW EXISTING INPUT DATA? (0=NO, 1=YES): 1


BASIC INPUT DATA:

     NO. OF BOLT ROWS       =  3
     JOINT LOAD (LB./IN.) =  20000.
     JOINT TEMP.(DEG. F.) =  30.
     JOINT TENSION FACTOR = 1.25
     BOLT MATERIAL         = 1 (TITANIUM)
     25 % 0-DEGREE PLIES FOR INNER GRAPHITE PATTERN
     37 % 0-DEGREE PLIES FOR OUTER GRAPHITE PATTERN

BOLT ROW DATA:

   STEP     STEP      BOLT      BOLT      BOLT  % GRAPHITE THICKNESS %
    NO.    LENGTH     DIAM.    SPACING    W/D       INNER      OUTER

     1      2.00      .375      2.50      0.       .400       .200
     2      2.00      .250      3.00      0.       .300       .400
     3      2.00      .375      2.50      0.       .200       .800

UPDATE BASIC DATA? (0=NO, 1=YES): 0


UPDATE STEP DATA? (0=NO, 1=YES): 1

ENTER STEP NO. (0 = END): 2

ENTER L, D, SP, TI, TO FOR STEP 2
2 .25 3 .3 .5

ENTER STEP NO. (0 = END): 0
```

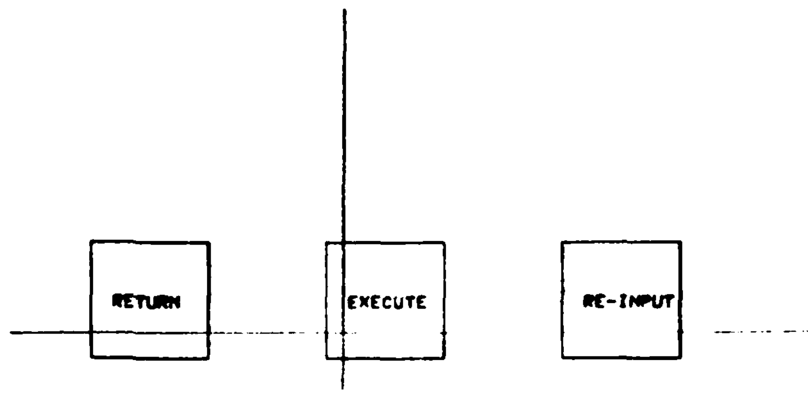


Figure 32. Bolted Stepped-Lap Editing

```
BOLTED -- STEPPED-LAP JOINT ANALYSIS
          ANALYSIS NAME - BOLT4-14

BASIC INPUT DATA:

     NO. OF BOLT ROWS       =  3
     JOINT LOAD (LB./IN.)   =  20000.
     JOINT TEMP.(DEG. F.)   =  30.
     JOINT TENSION FACTOR   = 1.25
     BOLT MATERIAL          = 1 (TITANIUM)
     25 % 0-DEGREE PLIES FOR INNER GRAPHITE PATTERN
     37 % 0-DEGREE PLIES FOR OUTER GRAPHITE PATTERN

BOLT ROW DATA:

   STEP     STEP      BOLT      BOLT      BOLT   * GRAPHITE THICKNESS *
   NO.     LENGTH     DIAM.    SPACING     W/D       INNER     OUTER

    1       2.00      .375      2.50       7.        .400      .200
    2       2.00      .250      3.00      12.        .300      .500
    3       2.00      .375      2.50       7.        .200      .800

SUMMARY OF BOLT ROW STRENGTHS

     BOLTS - % OF LOAD TRANSFERRED BY BOLTS
     INNER - % OF LOAD RETAINED BY INNER PLATE
     OUTER - % OF LOAD RETAINED BY OUTER PLATE
     M.S.  - MARGIN OF SAFETY

    ROW    BOLT    INNER    OUTER      M.S.      FAILURE MODE

     1      48      52        0       -.681      OUTER TENSION
     2      20      32       48       -.512      OUTER TENSION
     3      32       0       68       -.442      INNER BEARING

*  OUTPUT TO PRINT FILE *   OUTPUT TO SAVE FILE   *  RE-ANALYZE  *  RETURN  *
```

Figure 33. Bolted Stepped-Lap Output

```
INPUT DATA FROM A SOLUTION ON SAVE FILE? (1=YES, 0=NO): 0

MODIFY EXISTING INPUT DATA? (1=YES, 0=ALL NEW): 1

   1.109 CP SECONDS ELAPSED.
ENTER ANALYSIS NAME: bolt4-d

VIEW EXISTING INPUT DATA? (0=NO, 1=YES): 1


BASIC INPUT DATA:

     NO. OF BOLT ROWS       =  3
     JOINT LOAD (LB./IN.) =  20000.
     JOINT TEMP.(DEG. F.) =  30.
     JOINT TENSION FACTOR = 1.25
     BOLT MATERIAL          = 1 (TITANIUM)
     25 % 0-DEGREE PLIES FOR INNER GRAPHITE PATTERN
     37 % 0-DEGREE PLIES FOR OUTER GRAPHITE PATTERN

BOLT ROW DATA:

   STEP     STEP      BOLT      BOLT     BOLT  % GRAPHITE THICKNESS %
    NO.    LENGTH     DIAM.    SPACING    W/D      INNER      OUTER

    1       2.00      .375      2.50      7.       .400       .200
    2       2.00      .250      3.00     12.       .300       .500
    3       2.00      .375      2.50      7.       .200       .800

UPDATE BASIC DATA? (0=NO, 1=YES): 1

ENTER 7 BASIC DATA VALUES: 2 10000 30 1.25 2 37 25

ENTER L, D, SP, TI, TO FOR EACH STEP.

STEP  1 : 2 .375 2.5 .6 .2

STEP  2 : 3 .25 3 .4 .6
```

RETURN   EXECUTE   RE-INPUT

Figure 34. Bolted Stepped-Lap Modifications

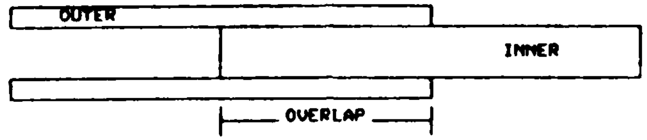
```
          BOLTED -- STEPPED-LAP JOINT ANALYSIS
              ANALYSIS NAME - BOLT4-D

BASIC INPUT DATA:

     NO. OF BOLT ROWS       -  2
     JOINT LOAD (LB./IN.) -  10000.
     JOINT TEMP.(DEG. F.) -  30.
     JOINT TENSION FACTOR - 1.25
     BOLT MATERIAL          - 2 (STEEL)
     37 % 0-DEGREE PLIES FOR INNER GRAPHITE PATTERN
     25 % 0-DEGREE PLIES FOR OUTER GRAPHITE PATTERN

BOLT ROW DATA:

    STEP     STEP       BOLT      BOLT      BOLT  * GRAPHITE THICKNESS *
     NO.    LENGTH      DIAM.    SPACING    W/D      INNER      OUTER

     1       2.00       .375      2.50       7.       .600       .200
     2       3.00       .250      3.30      12.       .400       .600

SUMMARY OF BOLT ROW STRENGTHS

     BOLTS - % OF LOAD TRANSFERRED BY BOLTS
     INNER - % OF LOAD RETAINED BY INNER PLATE
     OUTER - % OF LOAD RETAINED BY OUTER PLATE
     M.S.  - MARGIN OF SAFETY

    ROW    BOLT    INNER    OUTER      M.S.      FAILURE MODE

     1      63      37        0       -.508      OUTER TENSION
     2      37       0       63       -.443      INNER TENSION

* OUTPUT TO PRINT FILE *  OUTPUT TO SAVE FILE   * RE-ANALYZE * RETURN *
```

Figure 35. Bolted Stepped-Lap Output

```
                    ANALYSIS OPTIONS

                                  JOINT CODE
     CLASS                       BOLT    BOND

 STANDARD DOUBLE-LAP              1        5
 UNSUPPORTED SINGLE-LAP           2        6
 SUPPORTED SINGLE-LAP             3        7
 STEPPED-LAP                      4        8
 SCARFED                                   9

ENTER NUMERIC CODE (0 = RETURN): 5

INPUT DATA FROM A SOLUTION ON SAVE FILE? (1=YES, 0=NO): 0

OPTIONS:  0 = RETURN TO ANALYSIS OPTIONS
          1 = INPUT ALL CONSTRAINT DATA

ENTER OPTION NUMBER: 1

 17.481 CP SECONDS ELAPSED.
ENTER ANALYSIS NAME: bond5-15
```

Figure 36. Bonded Double-Lap Selection

BONDED -- STANDARD DOUBLE-LAP JOINT
ANALYSIS NAME = BOND5-15



---> INPUT JOINT CONSTRAINTS:

	VALUE	MOD.
☐ LOAD TYPE (1, 0, -1)	1	
☐ LOAD (LB./IN.)	12000	
☐ OVERLAP (IN.)	3	

---> INPUT ADHESIVE PROPERTIES:

	VALUE	MOD.
☐ MAX. SHEAR STRAIN	1.5	
☐ BOND THICKNESS	0	
☐ OPERATING TEMP.	250	
☐ CURE TEMP.	300	
☐ PEEL MODULUS	500000	
☐ ELASTIC SHEAR STRENGTH	4500	
☐ LINEAR ELASTIC MODULUS	70000	
☐ EL.-PL. SHEAR STRENGTH	6000	
☐ NON-LINEAR EL. MODULUS	50000	
☐ PEEL STRENGTH	10000	

---> INPUT ADHEREND PROPERTIES:

INNER

	VALUE	MOD.
☐ THICKNESS (IN.)	.2	
☐ YOUNG'S MODULUS	.105e+8	
☐ POISSON'S RATIO	.3	
☐ THERMAL COEFF.	.000013	
☐ YIELD STRENGTH	65000	66000
☐ TRANSV. MODULUS	.105e+8	
☐ TRANSV. STRENGTH	50000	

OUTER

	VALUE	MOD.
☐ THICKNESS (IN.)	.15	.25
☐ YOUNG'S MODULUS	0	
☐ POISSON'S RATIO	0	
☐ THERMAL COEFF.	.000006	
☐ YIELD STRENGTH	0	
☐ TRANSV. MODULUS	0	
☐ TRANSV. STRENGTH	0	

RETURN EXECUTE RE-DISPLAY

Figure 37. Bonded Double-Lap Input (A11)

```
                    BONDED -- STANDARD DOUBLE-LAP JOINT
                       ANALYSIS NAME - BONDS-15
  BASIC DATA:  LOAD TYPE      =  1 (TENSION)
               LOAD (LB/IN) = 12000.
               OVERLAP (IN) =  3.000

  ADHESIVE PROPERTIES:
        MAX. SHEAR STRAIN              1.50      ELASTIC SHEAR STRENGTH (PSI)    4500.
        BOND THICKNESS      (IN.)      .005      LINEAR ELASTIC MODULUS (PSI)   70000.
        OPERATING TEMP.     (F.)       250.      EL.-PL. SHEAR STRENGTH (PSI)    6000.
        CURE TEMP.          (F.)       300.      NON-LINEAR EL. MODULUS (PSI)   50000.
        PEEL MODULUS        (PSI)      500000.   PEEL STRENGTH          (PSI)   10000.

  ADHEREND PROPERTIES:                 (INNER)     (OUTER)
        THICKNESS           (IN.)      .20         .25
        YOUNG'S MODULUS     (PSI)      .105E+08    .105E+08
        POISSON'S RATIO                .30         .30
        THERMAL COEFF.                 .0000130    .0000060
        YIELD STRENGTH      (PSI)      66000.      66000.
        TRANSV. MODULUS     (PSI)      .105E+08    .105E+08
        TRANSV. STRENGTH    (PSI)      50000.      50000.

  JOINT ANALYSIS:
        OPTIMUM OVERLAP (IN.) =  2.74

        ADHESIVE SHEAR TYPE-     STRENGTH(LB/IN)  STRAIN
           ELASTIC-PLASTIC          23275.
           LINEAR ELASTIC            3651.         .064
           NON-LINEAR ELASTIC        5336.         .120
           PLASTIC                                1.380

        ADHERENDS-  INNER           13200.
                    OUTER           33000.

        LIMIT DUE TO
        ADHESIVE PEEL OR
        INTERLAMINAR TENSION-       42905.

 STRENGTH COMPUTATION
   OVERLAP (IN.) 3.00          BOND SHEAR STRENGTH (LB./IN.) 23260.
   BOND MORE CRITICAL WHERE INNER ADHEREND EXTENDS FROM JOINT

 STRESS ANALYSIS
   APPLIED LOAD (LB./IN.) 12000.          OVERLAP (IN.) 3.00
   ELASTIC-PLASTIC SOLUTION, MAX. ADHESIVE SHEAR STRAIN  .420
                             MAX. ADHESIVE SHEAR STRESS  6000.
   ADHESIVE MORE CRITICAL WHERE INNER ADHEREND EXTENDS FROM JOINT

 $  OUTPUT TO PRINT FILE $   OUTPUT TO SAVE FILE    $  RE-ANALYZE  $  RETURN  $
```

Figure 38.   Bonded Double-Lap Output

```
INPUT DATA FROM A SOLUTION ON SAVE FILE? (1=YES, 0=NO): 0

OPTIONS:  0 - RETURN TO ANALYSIS OPTIONS
          1 - INPUT ALL CONSTRAINT DATA
          2 - EDIT AVAILABLE DATA

ENTER OPTION NUMBER: 2


ENTER LOAD TYPE (1, 0, -1): -1

  2.926 CP SECONDS ELAPSED.
ENTER ANALYSIS NAME: bond15-d
```

Figure 39. Bonded Double-Lap Re-Analyze Page

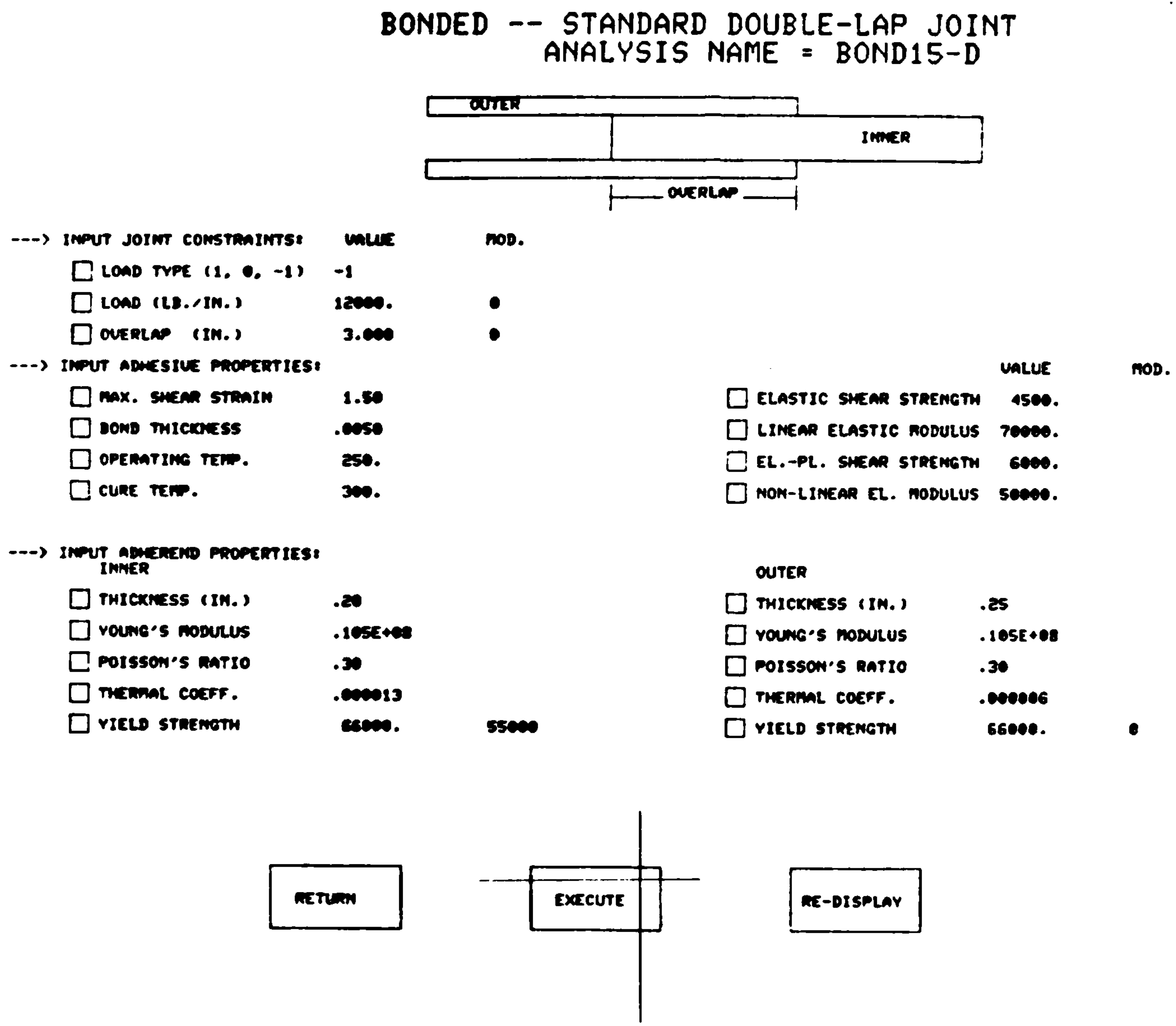
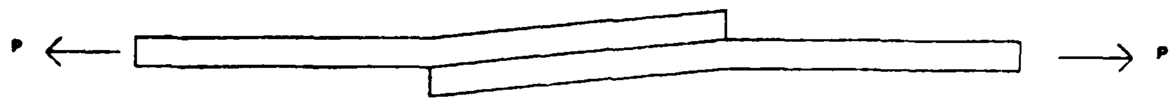


Figure 40. Bonded Double-Lap Re-Display & Modify

```
                BONDED -- STANDARD DOUBLE-LAP JOINT
                    ANALYSIS NAME = BONDIS-D

BASIC DATA:  LOAD TYPE     = -1 (COMPRESSION)
             LOAD (LB/IN)  =      0.
             OVERLAP (IN)  =  0.000

ADHESIVE PROPERTIES:
        MAX. SHEAR STRAIN            1.50      ELASTIC SHEAR STRENGTH (PSI)    4500.
        BOND THICKNESS     (IN.)     .005      LINEAR ELASTIC MODULUS (PSI)   70000.
        OPERATING TEMP.    (F.)      250.      EL.-PL. SHEAR STRENGTH (PSI)    6000.
        CURE TEMP.         (F.)      300.      NON-LINEAR EL. MODULUS (PSI)   50000.

ADHEREND PROPERTIES:                 (INNER)   (OUTER)
        THICKNESS          (IN.)     .20       .25
        YOUNG'S MODULUS    (PSI)     .105E+08  .105E+08
        POISSON'S RATIO              .30       .30
        THERMAL COEFF.               .0000130  .0000060
        YIELD STRENGTH     (PSI)     55000.    55000.

JOINT ANALYSIS:
        OPTIMUM OVERLAP (IN.) =  2.56

        ADHESIVE SHEAR TYPE-    STRENGTH(LB/IN)  STRAIN
           ELASTIC-PLASTIC          21805.
           LINEAR ELASTIC            2181.         .064
           NON-LINEAR ELASTIC        3866.         .120
           PLASTIC                                1.380

        ADHERENDS-  INNER           11000.
                    OUTER           27500.

*  OUTPUT TO PRINT FILE *  OUTPUT TO SAVE FILE   *  RE-ANALYZE  *  RETURN  *
```

Figure 41.   Bonded Double-Lap Output

BONDED -- UNSUPPORTED SINGLE-LAP JOINT ANALYSIS
ANALYSIS NAME = BOND6-16



---> JOINT DATA:	VALUE	MOD.
☐ LOAD (LB./IN.)	0	
☐ OVERLAP (IN.)	2	
---> ADHESIVE PROPERTIES:		
☐ BOND THICKNESS	0	
☐ MAX. SHEAR STRAIN	1.5	
☐ ELASTIC SHEAR STR.	4500	
☐ LINEAR EL. MODULUS	70000	
☐ EL.-PL. SHEAR STR.	6000	
☐ NON-LIN. EL. MOD.	50000	
☐ PEEL STRENGTH	500000	10000
☐ PEEL MODULUS	500000	

---> ADHEREND PROPERTIES:	VALUE	MOD.
☐ THICKNESS	.3	
☐ POISSON'S RATIO	.3	
☐ TENS. YIELD STR.	65000	
☐ YOUNG'S MODULUS	.1e+8	
☐ TRANSV. STRENGTH	50000	
☐ TRANSV. MODULUS	.1e+8	
☐ LAMINATING FACTOR	0	

RETURN | EXECUTE | RE-DISPLAY

Figure 42. Bonded Unsupported Single-Lap Input

```
BONDED -- UNSUPPORTED SINGLE-LAP JOINT ANALYSIS
            ANALYSIS NAME = BONDG-16

JOINT DATA:                    VALUE
      LOAD (LB./IN.),             0.
      OVERLAP  (IN.),           2.00

ADHESIVE PROPERTIES:                              ADHEREND PROPERTIES:   VALUE
      BOND THICKNESS        .0050                       THICKNESS          .30
      MAX. SHEAR STRAIN     1.500                       POISSON'S RATIO    .30
      ELASTIC SHEAR STR.    4500.                       TENS. YIELD STR.   65000.
      LINEAR EL. MODULUS    70000.                      YOUNG'S MODULUS    .100E+08
      EL.-PL. SHEAR STR.    6000.                       TRANSV. STRENGTH   50000.
      NON-LIN. EL. MOD.     50000.                      TRANSV. MODULUS    .100E+08
      PEEL STRENGTH         10000.                      LAMINATING FACTOR  1.0000
      PEEL MODULUS         500000.

JOINT STRENGTHS (LB./IN.):
      ADHEREND:  REMOTE TENSION      19500.
                 TENSION + BENDING    6685.

      BOND SHEAR:  ELASTIC            1602.
                   PLASTIC           12000.

      LIMIT DUE TO ADHESIVE PEEL
          OR INTERLAMINAR TENSION-    2182.

* OUTPUT TO PRINT FILE *  OUTPUT TO SAVE FILE  | * RE-ANALYZE * RETURN *
                             (COMPLETE)
```

Figure 43. Bonded Unsupported Single-Lap Output (P=0, OL≠0)

```
          BONDED -- UNSUPPORTED SINGLE-LAP JOINT ANALYSIS
                      ANALYSIS NAME = BONDG-17

JOINT DATA:                     VALUE
      LOAD (LB./IN.),           3000.
      OVERLAP  (IN.),           2.00

ADHESIVE PROPERTIES:                          ADHEREND PROPERTIES:   VALUE
      BOND THICKNESS        .0050                   THICKNESS           .30
      MAX. SHEAR STRAIN     1.500                   POISSON'S RATIO     .30
      ELASTIC SHEAR STR.    4500.                   TENS. YIELD STR.    65000.
      LINEAR EL. MODULUS    70000.                  YOUNG'S MODULUS     .100E+08
      EL.-PL. SHEAR STR.    6000.                   TRANSV. STRENGTH    50000.
      NON-LIN. EL. MOD.     50000.                  TRANSV. MODULUS     .100E+08
      PEEL STRENGTH         10000.                  LAMINATING FACTOR   1.0000
      PEEL MODULUS          500000

INTERNAL STRESSES (PSI):
    ADHEREND: AVE. APPLIED STRESS  10000.
              MAX. INDUCED STRESS  31921.

    ADHESIVE:  PEAK SHEAR STRESS   6000.
               PEAK SHEAR STRAIN    .124
               PEAK PEEL  STRESS   12969.


* OUTPUT TO PRINT FILE *  OUTPUT TO SAVE FILE   * RE-ANALYZE | * RETURN *
```

Figure 44. Bonded Unsupported Single-Lap Output (P≠0, OL≠0)

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```
BONDED -- UNSUPPORTED SINGLE-LAP JOINT ANALYSIS
            ANALYSIS NAME - BOND16-D

JOINT DATA:                 VALUE
      LOAD (LB./IN.),          0.
      OVERLAP  (IN.),        0.00

ADHESIVE PROPERTIES:                              ADHEREND PROPERTIES:   VALUE
      BOND THICKNESS       .0050                        THICKNESS          .30
      MAX. SHEAR STRAIN    1.500                        POISSON'S RATIO    .30
      ELASTIC SHEAR STR.    4500.                       TENS. YIELD STR.   65000.
      LINEAR EL. MODULUS   70000.                       YOUNG'S MODULUS    .100E+08
      EL.-PL. SHEAR STR.    6000.                       TRANSV. STRENGTH   50000.
      NON-LIN. EL. MOD.    50000.                       TRANSV. MODULUS    .100E+08
      PEEL STRENGTH        10000.                       LAMINATING FACTOR  1.0000
      PEEL MODULUS        500000.

JOINT STRENGTHS (LB./IN.):                            L/T RATIO
                                 10       20       40       60       80      100      150

   ADHEREND:  REMOTE TENSION   19500.   19500.   19500.   19500.   19500.   19500.   19500.
              TENSION + BENDING 7689.   10658.   14703.   16642.   17626.   18183.   18833.

   BOND SHEAR:  ELASTIC         1730.    2149.    2985.    3647.    4110.    4428.    4872.
                PLASTIC        13169.   14887.   19572.   36256.   38644.   40108.   42044.

   LIMIT DUE TO ADHESIVE PEEL
      OR INTERLAMINAR TENSION-  2474.    3720.   15542.   29530.   47737.   70049.  143517.

* OUTPUT TO PRINT FILE *  OUTPUT TO SAVE FILE   * RE-ANALYZE * RETURN *
```

Figure 45. Bonded Unsupported Single-Lap Output (P=0, OL=0)

BONDED -- UNSUPPORTED SINGLE-LAP JOINT ANALYSIS
ANALYSIS NAME = BOND16-E

JOINT DATA:	VALUE
LOAD (LB./IN.),	10000.
OVERLAP (IN.),	0.00

ADHESIVE PROPERTIES:		ADHEREND PROPERTIES:	VALUE
BOND THICKNESS	.0050	THICKNESS	.30
MAX. SHEAR STRAIN	1.500	POISSON'S RATIO	.30
ELASTIC SHEAR STR.	4500.	TENS. YIELD STR.	65000.
LINEAR EL. MODULUS	70000.	YOUNG'S MODULUS	.100E+08
EL.-PL. SHEAR STR.	6000.	TRANSV. STRENGTH	50000.
NON-LIN. EL. MOD.	50000.	TRANSV. MODULUS	.100E+08
PEEL STRENGTH	10000.	LAMINATING FACTOR	1.0000
PEEL MODULUS	500000.		

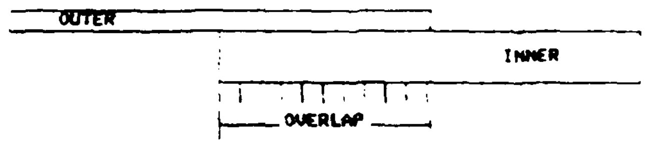
INTERNAL STRESSES (PSI):

		L/T RATIO						
		10	20	40	60	80	100	150
ADHEREND:	AVE. APPLIED STRESS	33333.	33333.	33333.	33333.	33333.	33333.	33333.
	MAX. INDUCED STRESS	80826.	61787.	47141.	41541.	38786.	37223.	35356.
ADHESIVE:	PEAK SHEAR STRESS	6000.	6000.	6000.	6000.	6000.	6000.	6000.
	PEAK SHEAR STRAIN	.554	.329	.210	.175	.159	.151	.141
	PEAK PEEL STRESS	28097.	16833.	8169.	4856.	3226.	2301.	1197.

* OUTPUT TO PRINT FILE * OUTPUT TO SAVE FILE * RE-ANALYZE * RETURN *

Figure 46. Bonded Unsupported Single-Lap Output (P≠0, OL=0)

BONDED -- SUPPORTED SINGLE-LAP JOINT
ANALYSIS NAME = BOND-7



---> INPUT JOINT CONSTRAINTS:

	VALUE	MOD.
☐ LOAD TYPE (1, 0, -1)	0	
☐ LOAD (LB./IN.)	3000.	
☐ OVERLAP (IN.)	2.000	

---> INPUT ADHESIVE PROPERTIES:

			VALUE	MOD.
☐ MAX. SHEAR STRAIN	1.50	☐ ELASTIC SHEAR STRENGTH	4500.	
☐ BOND THICKNESS	.0150	☐ LINEAR ELASTIC MODULUS	60000.	
☐ OPERATING TEMP.	200.	☐ EL.-PL. SHEAR STRENGTH	6000.	
☐ CURE TEMP.	150.	☐ NON-LINEAR EL. MODULUS	45000.	

---> INPUT ADHEREND PROPERTIES:

INNER			OUTER	
☐ THICKNESS (IN.)	.20		☐ THICKNESS (IN.)	.20
☐ YOUNG'S MODULUS	.100E+08		☐ YOUNG'S MODULUS	.100E+08
☐ POISSON'S RATIO	.30		☐ POISSON'S RATIO	.30
☐ THERMAL COEFF.	.000000		☐ THERMAL COEFF.	.000000
☐ YIELD STRENGTH	65000.	45000	☐ YIELD STRENGTH	65000.

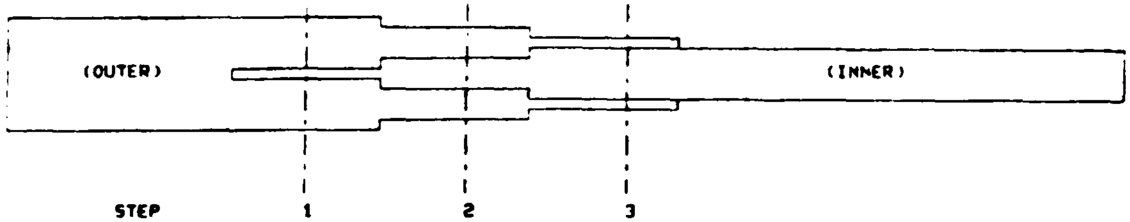
RETURN EXECUTE RE-DISPLAY

Figure 47. Bonded Supported Single-Lap Input

```
                  BONDED -- SUPPORTED SINGLE-LAP JOINT
                     ANALYSIS NAME = BOND-7

BASIC DATA:  LOAD TYPE     =  0 (IN-PLANE SHEAR)
             LOAD (LB/IN)  =  3000.
             OVERLAP (IN)  =  2.000

ADHESIVE PROPERTIES:
         MAX. SHEAR STRAIN              1.50        ELASTIC SHEAR STRENGTH (PSI)    4500.
         BOND THICKNESS    (IN.)        .015        LINEAR ELASTIC MODULUS (PSI)   60000.
         OPERATING TEMP.   (F.)         200.        EL.-PL. SHEAR STRENGTH (PSI)    6000.
         CURE TEMP.        (F.)         150.        NON-LINEAR EL. MODULUS (PSI)   45000.

ADHEREND PROPERTIES:                    (INNER)     (OUTER)
         THICKNESS         (IN.)        .20         .20
         YOUNG'S MODULUS   (PSI)        .100E+08    .100E+08
         POISSON'S RATIO                .30         .30
         THERMAL COEFF.                 .0000000    .0000000
         YIELD STRENGTH    (PSI)        45000.      45000.

JOINT ANALYSIS:
         OPTIMUM OVERLAP (IN.) =  3.65

         ADHESIVE SHEAR TYPE-    STRENGTH(LB/IN)   STRAIN
            ELASTIC-PLASTIC          19923.
            LINEAR ELASTIC            2791.          .075
            NON-LINEAR ELASTIC        4297.          .133
            PLASTIC                                 1.367

         ADHERENDS-  INNER            9000.
                     OUTER            9000.

STRENGTH COMPUTATION
  OVERLAP (IN.) 2.00          BOND SHEAR STRENGTH (LB./IN.) 12000.
  BOTH ENDS OF JOINT EQUALLY CRITICAL

STRESS ANALYSIS
  APPLIED LOAD (LB./IN.)  3000.         OVERLAP (IN.) 2.00
  ELASTIC-PLASTIC SOLUTION, MAX. ADHESIVE SHEAR STRAIN  .081
                            MAX. ADHESIVE SHEAR STRESS  4500.
  BOTH ENDS OF JOINT EQUALLY CRITICAL

*  OUTPUT TO PRINT FILE *   OUTPUT TO SAVE FILE    *  RE-ANALYZE  *  RETURN  *



      (COMPLETE)                 (COMPLETE)
```

Figure 48. Bonded Supported Single-Lap Output

BONDED STEPPED-LAP JOINT ANALYSIS
ANALYSIS NAME = BOND8-2



BASIC INPUT DATA:

1) LOAD TYPE (1=TENS, 0=SHEAR, -1=COMPR.)
2) NO. OF STEPS
3) TEMP. DIFFERENTIAL
4) ASSUME SYM. STRESS DISTR.? (0=NO, 1=YES)
5) SINGLE BOND SURFACE? (0=NO, 1=YES)

ADHESIVE PROPERTIES:

1) BOND THICKNESS (ETA)
2) PEAK SHEAR STRESS (TAU MAX.)
3) ELASTIC SHEAR MODULUS (G)
4) MAXIMUM SHEAR STRAIN (GAMMA MAX.)

ADHEREND PROPERTIES:

1) THERMAL EXPANSION COEFFICIENTS
2) STEP DATA: L = LENGTH
T = EFF. THICKNESS
ET = EXT. STIFFNESS
STR = STRENGTH

ENTER 5 BASIC DATA VALUES: -1 4 10 0 0

ENTER 4 ADHESIVE VALUES: .01 5000 55000 1.5

ENTER OUTER & INNER COEFF. : .000013 .000006

ENTER L, T(O), T(I), ET(O), ET(I), STR(O), STR(I), FOR EACH STEP.

STEP 1 : 2 .7 .2 1050000 1100000 7000 6500

STEP 2 : 2.5 .5 .3 1000000 950000 7500 6000

STEP 3 : 2.5 .3 .4 1100000 1140000 7000 6000

STEP 4 : 3 .1 .5 1200000 1100000 6000 7000

RETURN   EXECUTE   RE-INPUT

Figure 49. Bonded Stepped-Lap Joint Input

```
VIEW EXISTING INPUT DATA? (0=NO, 1=YES): 1

        BONDED STEPPED-LAP JOINT ANALYSIS


        BASIC INPUT DATA:

             LOAD TYPE     = COMPRESSION
             NO. OF STEPS =  4
             TEMP. DIFF.  =    10.
             2-BOND SURFACE


        ADHESIVE PROPERTIES:

             BOND THICKNESS          (ETA)           .0100
             PEAK SHEAR STRESS       (TAU MAX.)      5000.
             ELASTIC SHEAR MODULUS   (G)               55000.
             MAXIMUM SHEAR STRAIN    (GAMMA MAX.)   1.500
             ELASTIC SHEAR STRAIN    (GAMMA EL.)    0.000


        ADHEREND PROPERTIES:

             OUTER THERMAL EXPANSION COEFF. = .0000130
             INNER THERMAL EXPANSION COEFF. = .0000060

                         ** THICKNESS **      EXTENSIONAL STIFFNESS       *** STRENGTH ***
 STEP     LENGTH      OUTER      INNER        OUTER          INNER        OUTER       INNER

   1      2.0000      .7000      .2000      1050000.       1100000.       7000.       6500.
   2      2.5000      .5000      .3000      1000000.        950000.       7500.       6000.
   3      2.5000      .3000      .4000      1100000.       1140000.       7000.       6800.
   4      3.0000      .1000      .5000      1200000.       1100000.       6000.       7000.
UPDATE BASIC DATA? (0=NO, 1=YES): 1

ENTER 5 BASIC DATA VALUES: -1 4 -50 0 0

UPDATE ADHESIVE VALUES? (0=NO, 1=YES): 0

UPDATE THERMAL COEFF.? (0=NO, 1=YES): 0

UPDATE STEP DATA? (0=NO, 1=YES): 1

ENTER STEP NO. (0 = END): 2

ENTER L, T(O), T(I), ET(O), ET(I), STR(O), STR(I), FOR STEP  2
2.5 .5 .3 1050000 980000 7500 6000

ENTER STEP NO. (0 = END): 0
```

RETURN   EXECUTE   RE-INPUT

Figure 50. Bonded Stepped-Lap Joint Re-Input (Editing)

ADHESIVE-BONDED STEPPED-LAP JOINT ANALYSIS
ANALYSIS NAME = BONDR-2

BASIC INPUT DATA:

LOAD TYPE = COMPRESSION
NO. OF STEPS = 4
TEMP. DIFF. = -50.
2-BOND SURFACE

ADHESIVE PROPERTIES:

BOND THICKNESS	(ETA)	.0100
PEAK SHEAR STRESS	(TAU MAX.)	5000.
ELASTIC SHEAR MODULUS	(G)	55000.
MAXIMUM SHEAR STRAIN	(GAMMA MAX.)	1.500
ELASTIC SHEAR STRAIN	(GAMMA EL.)	.091

ADHEREND PROPERTIES:

OUTER THERMAL EXPANSION COEFF. = .0000130
INNER THERMAL EXPANSION COEFF. = .0000060

STEP	LENGTH	** THICKNESS ** OUTER	INNER	EXTENSIONAL STIFFNESS OUTER	INNER	*** STRENGTH *** OUTER	INNER
1	2.0000	.7000	.2000	1050000.	1100000.	7000.	6500.
2	2.5000	.5000	.3000	1050000.	980000.	7300.	6000.
3	2.5000	.3000	.4000	1100000.	1140000.	7000.	6800.
4	3.0000	.1000	.5000	1200000.	1100000.	6000.	7000.

Figure 51. Bonded Stepped-Lap Joint Output - Input Data

ELASTIC ANALYSIS

STEP	LENGTH	THICKO	THICKI	TAU	GAMMA	DELTAO	DELTAI	*** OUTER LOAD	STRENGTH ***	*** INNER LOAD	STRENGTH ***
1	.5000	.7000	.2000	5000.	.091	0.0000	-.0009	3952.	7000.	0.	6500.
2	.5000	.7000	.2000	520.	.009	-.0016	-.0017	1972.	7000.	1980.	6500.
3	.5000	.7000	.2000	53.	.001	-.0028	-.0028	1767.	7000.	2185.	6500.
4	.5000	.7000	.2000	-9.	-.000	-.0039	-.0039	1751.	7000.	2201.	6500.
5	.6250	.5000	.3000	-143.	-.003	-.0051	-.0051	1805.	7300.	2146.	6000.
6	.6250	.5000	.3000	-8.	-.000	-.0066	-.0066	1863.	7300.	2089.	6000.
7	.6250	.5000	.3000	-0.	-.000	-.0081	-.0081	1866.	7300.	2086.	6000.
8	.6250	.5000	.3000	8.	.000	-.0096	-.0096	1863.	7300.	2088.	6000.
9	.6250	.3000	.4000	138.	.003	-.0111	-.0112	1807.	7000.	2145.	6800.
10	.6250	.3000	.4000	9.	.000	-.0126	-.0126	1749.	7000.	2203.	6800.
11	.6250	.3000	.4000	0.	.000	-.0139	-.0139	1745.	7000.	2207.	6800.
12	.6250	.3000	.4000	-8.	-.000	-.0153	-.0153	1748.	7000.	2204.	6800.
13	.7500	.1000	.5000	-128.	-.002	-.0168	-.0167	1802.	6000.	2149.	7000.
14	.7500	.1000	.5000	-5.	-.000	-.0184	-.0184	1859.	6000.	2093.	7000.
15	.7500	.1000	.5000	6.	.000	-.0200	-.0200	1858.	6000.	2094.	7000.
16	.7500	.1000	.5000	153.	.003	-.0217	-.0217	1791.	6000.	2161.	7000.
17	0.0000	0.0000	.5000	4074.	.074	-.0230	-.0237	-0.	0.	3952.	7000.

INCLUDED IN SUMMARY

Figure 52. Bonded Stepped-Lap Joint - Elastic Analysis

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ELASTIC-PLASTIC ANALYSIS

STEP	LENGTH	THICKO	THICKI	TAU	GAMMA	DELTAO	DELTAI	*** OUTER *** LOAD	STRENGTH	*** INNER *** LOAD	STRENGTH
1	.1559	.7000	.2000	5000.	.178	0.0000	-.0018	7000.	7000.	0.	6500.
2	.3441	.7000	.2000	5000.	.091	-.0010	-.0019	5440.	7000.	1559.	6500.
3	0.0000	.7000	.2000	1054.	.019	-.0027	-.0029	3696.	7000.	3303.	6500.
4	.5000	.7000	.2000	1054.	.019	-.0027	-.0029	3696.	7000.	3303.	6500.
5	0.0000	.7000	.2000	107.	.002	-.0046	-.0046	3280.	7000.	3720.	6500.
6	0.0000	.7000	.2000	107.	.002	-.0046	-.0046	3280.	7000.	3720.	6500.
7	.5000	.7000	.2000	107.	.002	-.0046	-.0046	3280.	7000.	3720.	6500.
8	0.0000	.7000	.2000	-14.	-.000	-.0065	-.0065	3247.	7000.	3753.	6500.
9	0.0000	.7000	.2000	-14.	-.000	-.0065	-.0065	3247.	7000.	3753.	6500.
10	.5000	.7000	.2000	-14.	-.000	-.0065	-.0065	3247.	7000.	3753.	6500.
11	0.0000	.7000	.2000	-243.	-.004	-.0084	-.0083	3339.	7000.	3661.	6500.
12	0.0000	.7000	.2000	-243.	-.004	-.0084	-.0083	3339.	7000.	3661.	6500.
13	.6250	.5000	.3000	-243.	-.004	-.0084	-.0083	3339.	7300.	3661.	6000.
14	0.0000	.5000	.3000	-13.	-.000	-.0108	-.0108	3437.	7300.	3562.	6000.
15	0.0000	.5000	.3000	-13.	-.000	-.0108	-.0108	3437.	7300.	3562.	6000.
16	.6250	.5000	.3000	-13.	-.000	-.0108	-.0108	3437.	7300.	3562.	6000.
17	0.0000	.5000	.3000	-0.	-.000	-.0133	-.0133	3443.	7300.	3557.	6000.
18	0.0000	.5000	.3000	-0.	-.000	-.0133	-.0133	3443.	7300.	3557.	6000.
19	.6250	.5000	.3000	-0.	-.000	-.0133	-.0133	3443.	7300.	3557.	6000.
20	0.0000	.5000	.3000	12.	.000	-.0157	-.0157	3438.	7300.	3562.	6000.
21	0.0000	.5000	.3000	12.	.000	-.0157	-.0157	3438.	7300.	3562.	6000.
22	.6250	.5000	.3000	12.	.000	-.0157	-.0157	3438.	7300.	3562.	6000.
23	0.0000	.5000	.3000	229.	.004	-.0182	-.0182	3345.	7300.	3655.	6000.
24	0.0000	.5000	.3000	229.	.004	-.0182	-.0182	3345.	7300.	3655.	6000.
25	.6250	.3000	.4000	229.	.004	-.0182	-.0182	3345.	7000.	3655.	6800.
26	0.0000	.3000	.4000	14.	.000	-.0204	-.0204	3248.	7000.	3752.	6800.
27	0.0000	.3000	.4000	14.	.000	-.0204	-.0204	3248.	7000.	3752.	6800.
28	.6250	.3000	.4000	14.	.000	-.0204	-.0204	3248.	7000.	3752.	6800.
29	0.0000	.3000	.4000	-0.	-.000	-.0227	-.0227	3242.	7000.	3757.	6800.
30	0.0000	.3000	.4000	-0.	-.000	-.0227	-.0227	3242.	7000.	3757.	6800.
31	.6250	.3000	.4000	-0.	-.000	-.0227	-.0227	3242.	7000.	3757.	6800.
32	0.0000	.3000	.4000	-14.	-.000	-.0249	-.0249	3248.	7000.	3752.	6800.
33	0.0000	.3000	.4000	-14.	-.000	-.0249	-.0249	3248.	7000.	3752.	6800.
34	.6250	.3000	.4000	-14.	-.000	-.0249	-.0249	3248.	7000.	3752.	6800.
35	0.0000	.3000	.4000	-231.	-.004	-.0272	-.0272	3346.	7000.	3654.	6800.
36	0.0000	.3000	.4000	-231.	-.004	-.0272	-.0272	3346.	7000.	3654.	6800.
37	.7500	.1000	.5000	-231.	-.004	-.0272	-.0272	3346.	6000.	3654.	7000.
38	0.0000	.1000	.5000	-8.	-.000	-.0298	-.0298	3447.	6000.	3553.	7000.
39	0.0000	.1000	.5000	-8.	-.000	-.0298	-.0298	3447.	6000.	3553.	7000.
40	.7500	.1000	.5000	-8.	-.000	-.0298	-.0298	3447.	6000.	3553.	7000.
41	0.0000	.1000	.5000	11.	.000	-.0325	-.0325	3446.	6000.	3554.	7000.
42	0.0000	.1000	.5000	11.	.000	-.0325	-.0325	3446.	6000.	3554.	7000.
43	.7500	.1000	.5000	11.	.000	-.0325	-.0325	3446.	6000.	3554.	7000.
44	0.0000	.1000	.5000	312.	.006	-.0351	-.0351	3308.	6000.	3691.	7000.
45	0.0000	.1000	.5000	312.	.006	-.0351	-.0351	3308.	6000.	3691.	7000.
46	.0333	.1000	.5000	312.	.006	-.0351	-.0351	3308.	6000.	3691.	7000.
47	.1167	.1000	.5000	5000.	.091	-.0369	-.0378	1167.	6000.	5833.	7000.
48	0.0000	.1000	.5000	5000.	.149	-.0370	-.0385	-0.	6000.	7000.	7000.
49	0.0000	0.0000	.5000	5000.	.149	-.0370	-.0385	-0.	0.	7000.	7000.

Figure 53. Bonded Stepped-Lap Joint - Elastic-Plastic Analysis

ELASTIC-PLASTIC ANALYSIS
(INFINITE ADHEREND STRENGTH)

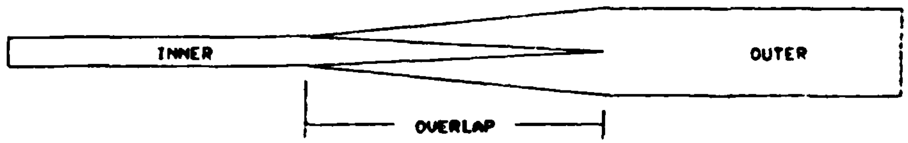
STEP	LENGTH	THICKO	THICKI	TAU	GAMMA	DELTAO	DELTAI	OUTER LOAD	INNER LOAD
1	.5000	.7000	.2000	9000.	1.500	0.0000	-.0150	24069.	0.
2	0.0000	.7000	.2000	9000.	.569	-.0106	-.0163	19069.	5000.
3	0.0000	.7000	.2000	9000.	.569	-.0106	-.0163	19069.	5000.
4	.5000	.7000	.2000	9000.	.569	-.0106	-.0163	19069.	5000.
5	0.0000	.7000	.2000	9000.	.103	-.0188	-.0198	14069.	10000.
6	0.0000	.7000	.2000	9000.	.103	-.0188	-.0198	14069.	10000.
7	.0285	.7000	.2000	9000.	.103	-.0188	-.0198	14069.	10000.
8	.4715	.7000	.2000	9000.	.091	-.0192	-.0201	13784.	10285.
9	0.0000	.7000	.2000	920.	.009	-.0251	-.0252	11861.	12208.
10	.5000	.7000	.2000	920.	.009	-.0251	-.0252	11861.	12208.
11	0.0000	.7000	.2000	-639.	-.012	-.0311	-.0309	11904.	12166.
12	0.0000	.7000	.2000	-639.	-.012	-.0311	-.0309	11904.	12166.
13	.6250	.9000	.3000	-639.	-.012	-.0311	-.0309	11904.	12166.
14	0.0000	.9000	.3000	-33.	-.001	-.0390	-.0390	12159.	11910.
15	0.0000	.9000	.3000	-33.	-.001	-.0390	-.0390	12159.	11910.
16	.6250	.9000	.3000	-33.	-.001	-.0390	-.0390	12159.	11910.
17	0.0000	.9000	.3000	-0.	-.000	-.0470	-.0470	12171.	11898.
18	0.0000	.9000	.3000	-0.	-.000	-.0470	-.0470	12171.	11898.
19	.6250	.9000	.3000	-0.	-.000	-.0470	-.0470	12171.	11898.
20	0.0000	.9000	.3000	32.	.001	-.0550	-.0551	12159.	11910.
21	0.0000	.9000	.3000	32.	.001	-.0550	-.0551	12159.	11910.
22	.6250	.9000	.3000	32.	.001	-.0550	-.0551	12159.	11910.
23	0.0000	.9000	.3000	629.	.011	-.0630	-.0631	11908.	12161.
24	0.0000	.9000	.3000	629.	.011	-.0630	-.0631	11908.	12161.
25	.6250	.3000	.4000	629.	.011	-.0630	-.0631	11908.	12161.
26	0.0000	.3000	.4000	39.	.001	-.0701	-.0701	11642.	12428.
27	0.0000	.3000	.4000	39.	.001	-.0701	-.0701	11642.	12428.
28	.6250	.3000	.4000	39.	.001	-.0701	-.0701	11642.	12428.
29	0.0000	.3000	.4000	-1.	-.000	-.0771	-.0771	11626.	12443.
30	0.0000	.3000	.4000	-1.	-.000	-.0771	-.0771	11626.	12443.
31	.6250	.3000	.4000	-1.	-.000	-.0771	-.0771	11626.	12443.
32	0.0000	.3000	.4000	-90.	-.001	-.0841	-.0841	11647.	12423.
33	0.0000	.3000	.4000	-90.	-.001	-.0841	-.0841	11647.	12423.
34	.6250	.3000	.4000	-90.	-.001	-.0841	-.0841	11647.	12423.
35	0.0000	.3000	.4000	-807.	-.015	-.0912	-.0910	11988.	12081.
36	0.0000	.3000	.4000	-807.	-.015	-.0912	-.0910	11988.	12081.
37	.7500	.1000	.5000	-807.	-.015	-.0912	-.0910	11988.	12081.
38	0.0000	.1000	.5000	-9.	-.000	-.0993	-.0993	12333.	11736.
39	0.0000	.1000	.5000	-9.	-.000	-.0993	-.0993	12333.	11736.
40	.7500	.1000	.5000	-9.	-.000	-.0993	-.0993	12333.	11736.
41	0.0000	.1000	.5000	977.	.010	-.1075	-.1076	12092.	11977.
42	0.0000	.1000	.5000	977.	.010	-.1075	-.1076	12092.	11977.
43	.4927	.1000	.5000	977.	.010	-.1075	-.1076	12092.	11977.
44	.2573	.1000	.5000	9000.	.091	-.1125	-.1134	10073.	13997.
45	0.0000	.1000	.5000	9000.	.251	-.1145	-.1171	7500.	16569.
46	.7500	.1000	.5000	9000.	.251	-.1145	-.1171	7500.	16569.
47	0.0000	.1000	.5000	9000.	1.376	-.1174	-.1311	-0.	24069.
48	0.0000	.1000	.5000	9000.	1.376	-.1174	-.1311	-0.	24069.
49	0.0000	0.0000	.5000	9000.	1.376	-.1174	-.1311	-0.	24069.

Figure 54. Bonded Stepped-Lap Joint Output — El.-Pl. Analysis With Infinite Adherend Strength

```
              BONDED STEPPED-LAP JOINT ANALYSIS SUMMARY
                     ANALYSIS NAME = BONDB-2

                        ELASTIC SOLUTION

JOINT STRENGTH (LBS) =     3952.

ADHESIVE SHEAR STRESS (PSI):  ALLOWABLE  =   5000.
                              FIRST STEP =   5000.
                              LAST  STEP =   4074.


                     ELASTIC-PLASTIC SOLUTION

JOINT STRENGTH (LBS) =     7000.

ADHESIVE SHEAR STRAIN:  ALLOWABLE  =  1.500
                        FIRST STEP =   .178
                        LAST  STEP =   .149

CRITICAL STRENGTH (PSI):  ACTUAL  ALLOWABLE
                  OUTER:  7000.     7000.
                  INNER:  7000.     7000.


             *** INFINITE ADHEREND ALLOWABLE SOLUTION ***

JOINT STRENGTH (LBS) =    24069.

ADHESIVE SHEAR STRAIN:  ALLOWABLE  =  1.500
                        FIRST STEP =  1.500
                        LAST  STEP =  1.376

* OUTPUT TO PRINT FILE *  OUTPUT TO SAVE FILE   * RE-ANALYZE * RETURN *

                     (COMPLETE)



(COMPLETE)
```

Figure 55. Bonded Stepped-Lap Joint Output Summary

BONDED -- SYMMETRICAL SCARF JOINT
ANALYSIS NAME = BOND-19A



---) INPUT JOINT CONSTRAINTS:

	VALUE	MOD.
☐ LOAD TYPE (1, 0, -1)	1	
☐ LOAD (LB./IN.)	10000.	
☐ OVERLAP (IN.)	2.500	2.0

---) INPUT ADHESIVE PROPERTIES:

	VALUE
☐ MAX. SHEAR STRAIN	1.10
☐ BOND THICKNESS	.0050
☐ OPERATING TEMP.	70.
☐ CURE TEMP.	120.

	VALUE	MOD.
☐ ELASTIC SHEAR STRENGTH	4000.	
☐ LINEAR ELASTIC MODULUS	70000.	
☐ EL.-PL. SHEAR STRENGTH	5000.	
☐ NON-LINEAR EL. MODULUS	50000.	

---) INPUT ADHEREND PROPERTIES:

INNER

☐ THICKNESS (IN.)	.10
☐ YOUNG'S MODULUS	.150E+08
☐ POISSON'S RATIO	.40
☐ THERMAL COEFF.	.000000
☐ YIELD STRENGTH	150000.

OUTER

☐ THICKNESS (IN.)	.20
☐ YOUNG'S MODULUS	.100E+08
☐ POISSON'S RATIO	.30
☐ THERMAL COEFF.	.000013
☐ YIELD STRENGTH	70000.

RETURN   EXECUTE   RE-DISPLAY

Figure 56. Bonded Scarf Joint Input

```
                    BONDED -- SCARF JOINT
                    ANALYSIS NAME = BOND-19A

                        2 BOND SURFACES
BASIC DATA:
        LOAD TYPE     =  1 (TENSION)
        LOAD (LB/IN) = 10000.
        OVERLAP (IN) =  2.000

ADHESIVE PROPERTIES:
        MAX. SHEAR STRAIN          1.10       ELASTIC SHEAR STRENGTH (PSI)     4000.
        BOND THICKNESS    (IN.)    .005       LINEAR ELASTIC MODULUS (PSI)    70000.
        OPERATING TEMP.   (F.)      70.       EL.-PL. SHEAR STRENGTH (PSI)     5000.
        CURE TEMPERATURE  (F.)     120.       NON-LINEAR EL. MODULUS (PSI)    50000.

ADHEREND PROPERTIES:              (LEFT)       (RIGHT)
        THICKNESS                  .10          .20
        YOUNG'S MODULUS   (PSI)    .150E+08     .100E+08
        POISSON'S RATIO            .40          .30
        THERMAL COEFF.             .0000000     .0000130
        YIELD STRENGTH    (PSI)    150000.      70000.

 INTERNAL STRESSES (PSI):
      REMOTE ADHEREND STRESS - LEFT  = 100000.
                             - RIGHT =  50000.

      PEAK ADHESIVE SHEAR:  OVERLAP     STRESS     STRAIN   END
                              2.00       3429.      .0490     L

 * OUTPUT TO PRINT FILE *  OUTPUT TO SAVE FILE   * RE-ANALYZE  * RETURN  *
```


Figure 57. Bonded Scarf Joint Output (Load≠0, Overlap≠0)

```
                         BONDED -- SCARF JOINT
                        ANALYSIS NAME = BOND-19C

                           2 BOND SURFACES

BASIC DATA:

        LOAD TYPE     =  1 (TENSION)

        LOAD (LB/IN) =      0.

        OVERLAP (IN) =  0.000

ADHESIVE PROPERTIES:

        MAX. SHEAR STRAIN          1.10       ELASTIC SHEAR STRENGTH (PSI)    4000.

        BOND THICKNESS    (IN.)    .005       LINEAR ELASTIC MODULUS (PSI)   70000.

        OPERATING TEMP.   (F.)      70.       EL.-PL. SHEAR STRENGTH (PSI)    5000.

        CURE TEMPERATURE  (F.)     120.       NON-LINEAR EL. MODULUS (PSI)   50000.

ADHEREND PROPERTIES:               (LEFT)       (RIGHT)

        THICKNESS                  .10          .20

        YOUNG'S MODULUS   (PSI)    .150E+08     .100E+08

        POISSON'S RATIO            .40          .30

        THERMAL COEFF.             .0000000     .0000130

        YIELD STRENGTH    (PSI)    150000.       70000.

 JOINT STRENGTHS (LB./IN.):

       REMOTE ADHEREND STRENGTH - LEFT  =  15000.
                                - RIGHT =  14000.

       ADHESIVE SHEAR STRENGTHS:  OVERLAP  * ELASTIC  (END) * TRANSITIONAL  (END) * EL.-PL.  (END) *

                                    1.00      5852.    L           6090.    L      10000.
                                    2.00     11803.    L          12089.    L      19849.    L
                                    4.00     23754.    L          24059.    L      34796.    L
                                    6.00     35736.    L          36045.    L      49913.    L
                                    8.00     47727.    L          48038.    L      64975.    L
                                   10.00     59721.    L          60034.    L      80012.    L
                                   15.00     89713.    L          90028.    L     117559.    L

*  OUTPUT TO PRINT FILE *  OUTPUT TO SAVE FILE   *  RE-ANALYZE  *  RETURN  *
```

Figure 58. Bonded Scarf Joint Output (Load=0, Overlap=0)

```
*** ENDS OF JOINT HAVE BEEN INTERCHANGED ***

                         BONDED -- SCARF JOINT
                        ANALYSIS NAME - BOND-19D

                         2 BOND SURFACES

BASIC DATA:
        LOAD TYPE     -  1 (TENSION)
        LOAD (LB/IN) -      0.
        OVERLAP (IN) -  2.000

ADHESIVE PROPERTIES:
        MAX. SHEAR STRAIN           1.10         ELASTIC SHEAR STRENGTH (PSI)    4000.
        BOND THICKNESS     (IN.)    .005         LINEAR ELASTIC MODULUS (PSI)   70000.
        OPERATING TEMP.    (F.)      70.         EL.-PL. SHEAR STRENGTH (PSI)    5000.
        CURE TEMPERATURE   (F.)     120.         NON-LINEAR EL. MODULUS (PSI)   50000.

ADHEREND PROPERTIES:                (LEFT)       (RIGHT)
        THICKNESS                   .10           .20
        YOUNG'S MODULUS    (PSI)    .150E+08      .100E+08
        POISSON'S RATIO             .40           .30
        THERMAL COEFF.              .0000000      .0000130
        YIELD STRENGTH     (PSI)    150000.        70000.

 JOINT STRENGTHS (LB./IN.):
      REMOTE ADHEREND STRENGTH - LEFT  =  15000.
                               - RIGHT =  14000.

      ADHESIVE SHEAR STRENGTHS:  OVERLAP  *  ELASTIC  (END)  *  TRANSITIONAL  (END)  *  EL.-PL.  (END)  *
                                   2.00      11803.    L          12089.       L        19849.    L

*  OUTPUT TO PRINT FILE *   OUTPUT TO SAVE FILE    *  RE-ANALYZE  *  RETURN  *
```

Figure 59. Bonded Scarf Joint Output (Load=0, Overlap≠0)

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```
                 COMPOSITE JOINT DESIGN PROGRAM

      ---->      CODE    OPTION
                   1 =  ANALYZE JOINT
                   2 =  SELECTIVE OUTPUT OF SOLUTIONS FROM SAVE FILE
                   3 =  CONSOLIDATE SOLUTIONS ON SAVE FILE
                   4 =  EXIT
ENTER CODE: 2
IS OUTPUT TO BE DISPLAYED? (1=YES; OTHERWISE WILL COPY TO PRINT FILE): ●
```


Figure 60. Selective Output Processing Option

SELECTIVE OUTPUT OF SOLUTIONS TO PRINT FILE

BOLT1-1 BOLT4-1 BOND5-1 BOND7-1 BOND8-1 BOND9-1 BOND9-2 BOND9-3 BOND9-4 BOND9-6

BOND9-7 BOND9-8 BOND9-9 BOND9-10 BOND9-9 BOND9-7

RETURN

EXECUTE

PIC NAMES FOR COPY TO PRINT FILE

SOLUTIONS BEING WRITTEN TO PRINT FILE
(COMPLETE)

Figure 61. Selective Output of Solutions To Print File

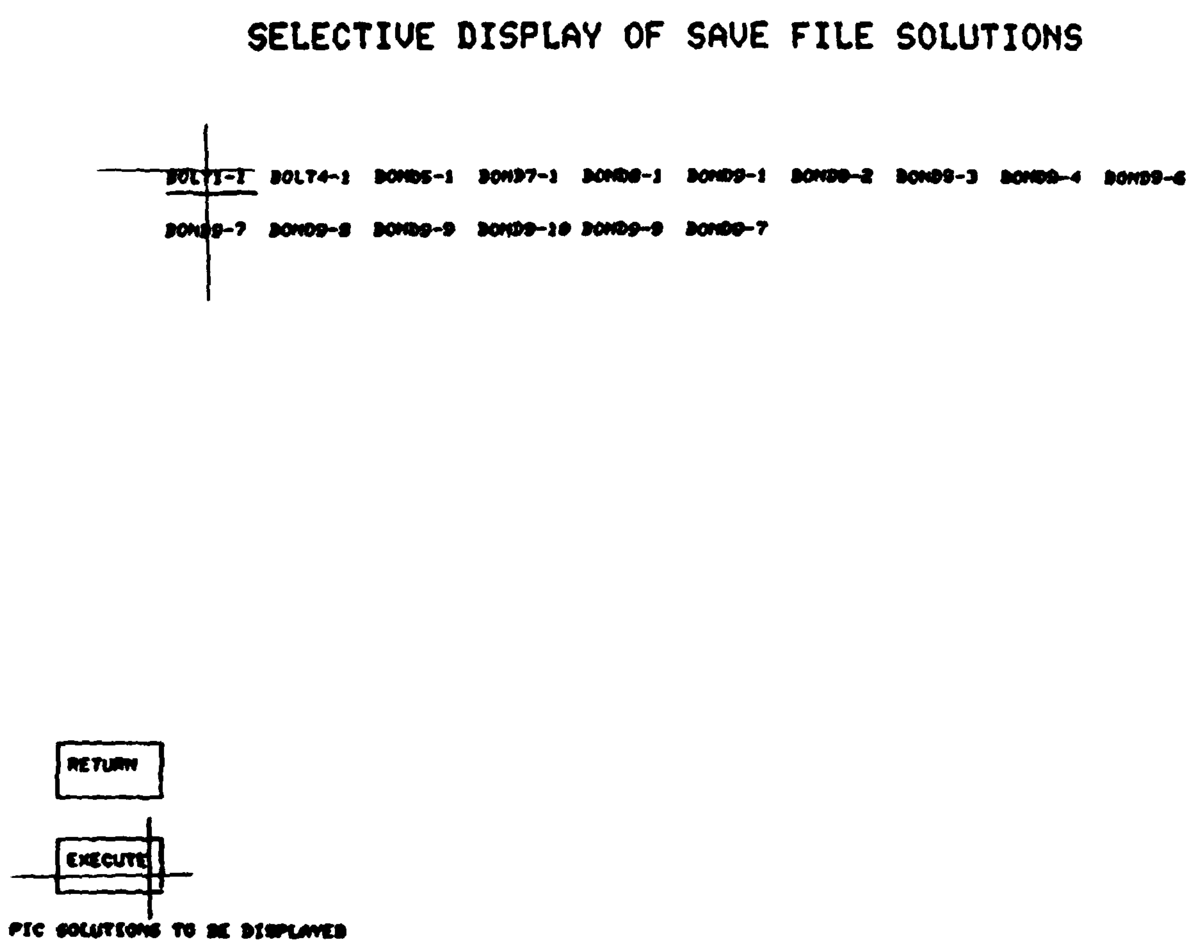

Figure 62. Selection of Save File Solutions For Display

```
        BALANCED BOLTED DOUBLE-LAP COMPOSITE JOINT ANALYSIS PRINTOUT
                        ANALYSIS NAME - BOLT1-1

CODE      INPUT DATA:                          VALUE

NX           JOINT LOAD  (LB./IN.)             2000.
FS           JOINT M.S. TENSION FACTOR          1.00
TEMP         JOINT TEMP  (DEG. F.)                0.
MATL         % 0-DEGREE GRAPHITE PLIES            0
BOLT         BOLT TYPE                         1 (TITANIUM)
N            NO. OF BOLT ROWS                     1

T            JOINT THICKNESS   (IN.)           .079
D            BOLT DIAMETER     (IN.)           .188
W            BOLT SPACING      (IN.)           .811
             W/D RATIO                        4.323
             6-D ROW SPACING                  1.125


          OUTPUT DATA:

             JOINT WEIGHT    (LB/IN)          .0099

               SUMMARY OF BOLT ROW STRENGTHS

          BOLT    % OF LOAD     MARGIN OF     FAILURE
          ROW    TRANSFERRED     SAFETY        MODE

           1         100          -.00        TENSION

*** END OF DATA ***
```

Figure 63. Example Solution Display

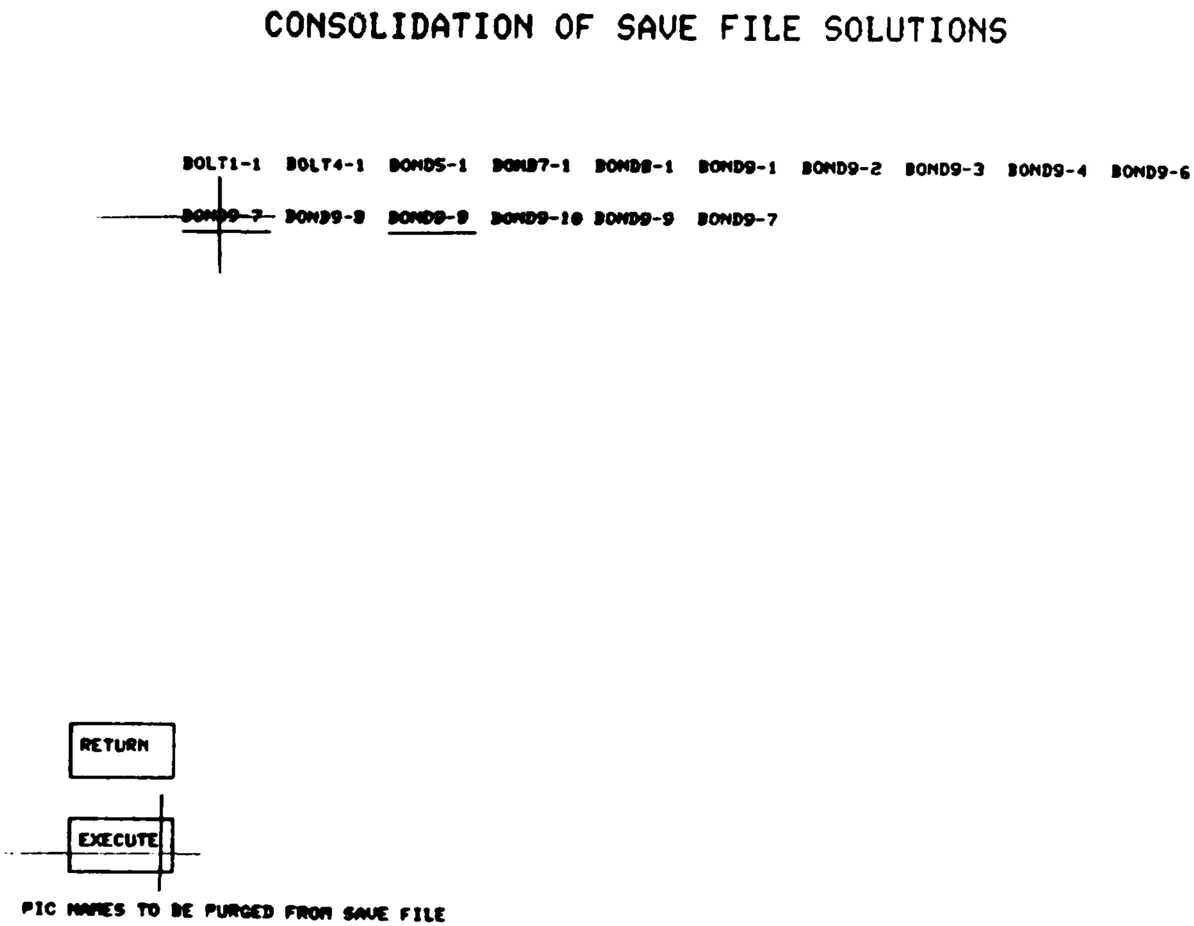

Figure 64. Consolidate Solutions On Save File

SECTION II

ANALYTICAL PROBLEM DESCRIPTION FOR BONDED JOINTS

PHYSICAL PROBLEM DESCRIPTION

Figure 65 illustrates the various types of bonded joint geometries covered by this program. The difference between a joint and a doubler is that, in a joint, the entire load is passed through the bond whereas in a doubler, only some of the load is so transferred.

The loads in the adherends are basically in-plane, with no lateral applied loads. However, in the overlap area, there can be bending deflections and transverse stresses in one or more of the adherends as a result of eccentricities in load path. The analyses cover remote loads which are tensile, compressive, or in-plane shear.

The adherends are treated as homogeneous orthrotropic materials rather than as multi-component fiber/matrix combinations. Experimentally determined material stress-strain curves for the adhesive and adherends are used to cover the possible failure modes of adhesive shear, adhesive peel, adherend in-plane failure away from the bonded overlap, and adherend interlaminar failure in the joint area. Thermal properties, as well as mechanical, are provided for so that the analyses can account for the initial stresses induced by the bonding of metals to composites. The adherends are treated as linearly elastic to failure, while the adhesive is modelled as an elastic-plastic material to account for its considerable non-linear deformation prior to failure. The linear treatment of the adherends does not impose any real restriction on the utility of the programs because a sustained yield load on the adherends causes steady and progressive failure of the bond as long as that load is maintained.

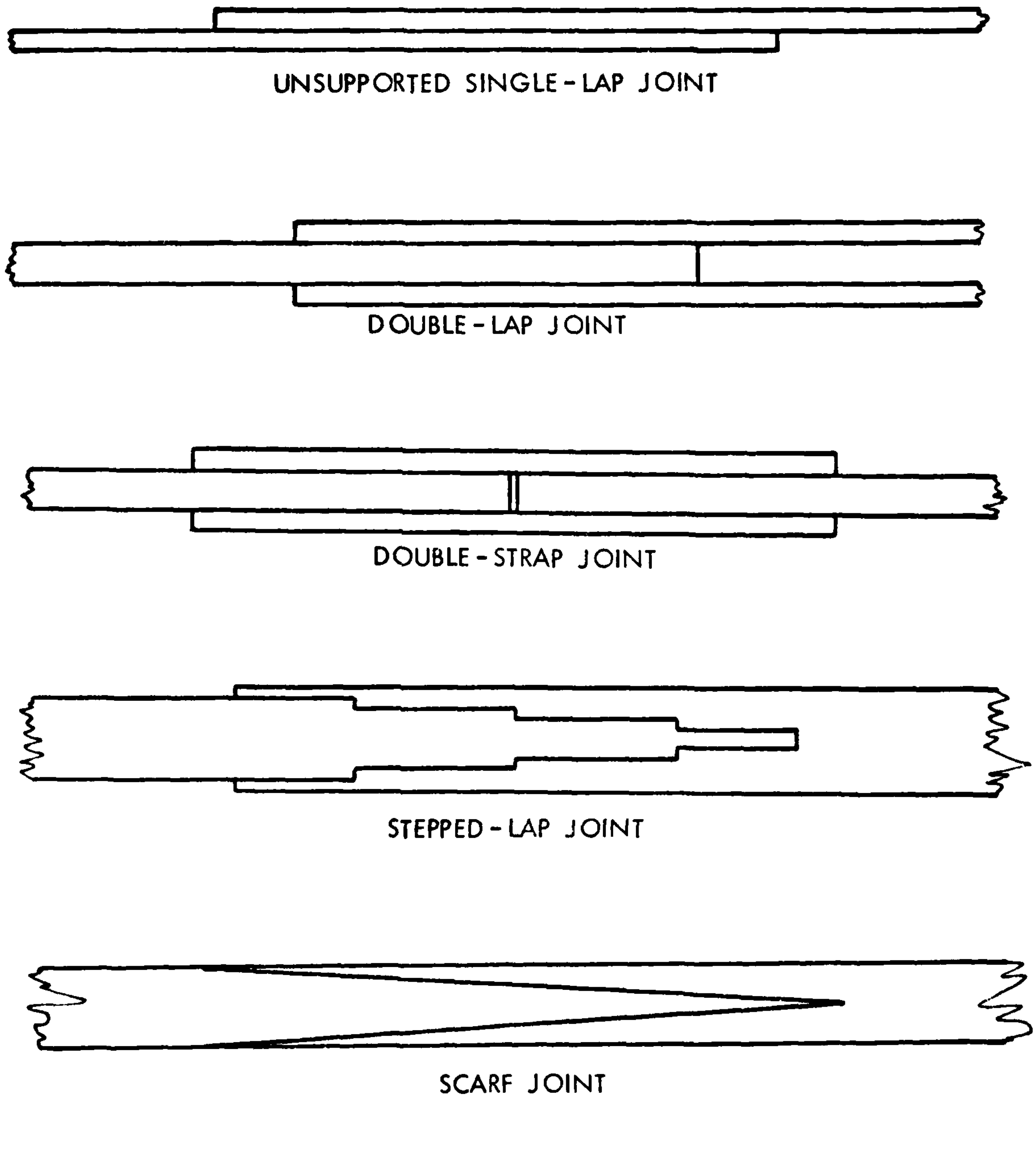

Figure 65. Bonded Joint Geometries

MATHEMATICAL MODEL DESCRIPTION

The mathematical models used are fully described[1-3], and the features accounted for here are outlined in the physical description. No published solutions cover all the governing variables precisely but it is felt that those of these analyses are the most important. The importance of accounting for adhesive non-linearity is paramount.

One key improvement found in these solutions and not found elsewhere is the accounting for adhesive plasticity in an explicit simple manner. Other more elaborate characterizations have been tried elsewhere. This has pre vented some solutions from being completed to workable form and made others too timecconsuming for production work. An explicit closed form analysis of double-lap bonded joints[1] has shown that any bi-linear (two straight lines) representation of adhesive shear characteristics leads to precisely the same joint strength provides that the adhesive models have the same failure stress, strain, and strain energy. Only the elastic-plastic limit of this family of solutions has led to explicit closed-form solutions for more complex joint geometries and this is why it has been adopted for this work.

A second key improvement pertains only to the unsupported single-lap joints. This is in the calculation of the bending moment at the ends of the overlap. Since this serves as a dominant boundary condition on the adhesive shear stresses and peel stresses as well as the adherend bending stresses, it must be determined as accurately as possible. With the exception of one Ph.D. thesis which handles this detail to the same accuracy[2], all other published solutions for single-lap bonded joints ase unnecessarily coarse approximations in determining that bending moment. This nullifies the

1. Hart-Smith, L. J., "Adhesive-Bonded Double-Lap Joints", NASA CR-112235, January 1973.
2. Hart-Smith, L. J., "Adhesive-Bonded Single-Lap Joints", NASA CR-112236, January 1973.
3. Hart-Smith, L. J., "Adhesive-Bonded Scarf and Stepped-Lap Joints", NASA CR-112237, January 1977.

quantitative value of the subsequent portions of those investigations, even when they are qualitatively correct elsewhere.

Other published bonded joint solutions contain up to two factors not accounted for here. One is the ply-by-ply stress distribution within the laminate, as opposed to the homogeneous orthotropic model used here. Published assessments of this effect indicate that provision for interlaminar shear deformation alone does not have a major impact on the adhesive shear stress distribution but that the variation of the interlaminar tension stresses through the thickness does have a significant effect on the elastic adhesive shear stresses. The result of accounting for this factor is that the adhesive shear stresses peak slightly inside the end of the overlap, instead of right at the end where equilibrium demands that there be no stresses. This effect is particularly significant for unsupported single-lap joints and is not negligible for double-lap joints either, provided that attention is restricted to linearly elastic adhesive behavior. Near the ultimate joint strength, however, the adhesive non-linear behavior makes this effect less and less significant. Certainly, it is more important to account for adhesive plasticity, then, than for the variation in peel stresses through the thickness. Accounting for the latter raises the order and complexity of the governing differential equations. So far, no analyses have been able to account for both of these effects simultaneously.

The second factor treated more precisely elsewhere is that the adhesive failure criteria here are for shear and peel separately, instead of in terms of an interaction formula. The justification for the present simpler approach is as follows. When peel stresses are significant in comparison with the shear stresses, the former enforce a joint strength reduction. Therefore,

the interest in peel stresses is mainly to identify those geometries which need modifying to alleviate such stresses. In the satisfactory joint geometries, the peel stresses can be neglected in comparison with the shear stresses and, in identifying those unsatisfactory geometries in which the peel stresses are predominant, the shear stresses can be ignored. There is only a small range of geometries in which both stresses are significant simultaneously and even those can be improved to reduce the strength loss due to the peel stresses.

The solutions are formulated in terms of differential equations from classical continium mechanics. Some explicit solutions are derived. Others are exact, but implicit, and require an iterative solution. The scarf joint solutions use a finite number of coefficients of a power series solution. Consequently, the scarf joint strengths are obtained as the integral of these stresses, *with considerable accuracy*, but the internal stress distributions are usually not sufficiently accurate and are, therefore, not specified. The stepped-lap programs encounter potential numerical accuracy problems because of the very high shear stress gradients, which sometimes caused failure to converge. All such cases known have been eliminated by artifically dividing the step lengths automatically to restrict the arguments of the exponential functions. The internal operations are tested to 16 significant digits and the overall solutions are accurate to at least 6 significant digits.

DESCRIPTION OF NUMERICAL METHODS

The details of the analysis methods are fully documented.[1-3]

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1. Hart-Smith, L. J., "Adhesive-Bonded Double-Lap Joints", NASA CR-112235, January 1973.

2. Hart-Smith, L. J., "Adhesive-Bonded Double-Lap Joints", NASA CR-11236, January 1973.

3. Hart-Smith, L. J., "Adhesive-Bonded Scarf and Stepped-Lap Joints", NASA CR-112237, January 1977.

LIMITATIONS

Other than the FORMAT limitations, there are no mathematical limitations on these programs. The input/output instructions are set up for U.S. customary units, rather than S.I. units, and changes would be necessary to accommodate other units.

SOLUTION ACCURACY

The solution printed will be accurate to at least the number of significant digits printed with only one exception. That exception is the case where the adherends are so thick and the thermal mismatch so great that the joint breaks apart without the application of any mechanical load. In most such cases, this situation is identified by obviously self-inconsistent answers and by abnormally long run times because of failure to converge. A concealed failure case is that in which the stiffness imbalance and thermal mismatch cancel each other out for one particular load direction. In some such instances, the removal of the mechanical load result in failure due to the thermally-induced stresses. There is no special provision involved automatically for such a case. However, re-running the problem for a near zero load or reversed temperature differential (to simulate reversal of the load) will bring such situations to light.

DEFINITION OF NOTATION

The notation used is fully explained.[1-3]

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1. Hart-Smith, L. J., "Adhesive-Bonded Double-Lap Joints", NASA CR-112235, January 1973.
2. Hart-Smith, L. J., "Adhesive-Bonded Double-Lap Joints", NASA CR-11236, January 1973.
3. Hart-Smith, L. J., "Adhesive-Bonded Scarf and Stepped-Lap Joints", NASA CR-112237, January 1977.

SECTION III

ANALYTICAL PROBLEM DESCRIPTION FOR BOLTED JOINTS

PHYSICAL PROBLEM DESCRIPTION

Four types of bolted joints are treated here. These joints represent some of the more common techniques of joining major load carrying structure constructed with an advanced composite material of graphite-epoxy. These four joint types which are illustrated in Figure 66 are:

- balanced double-lap
- supported single-lap
- unsupported single-lap
- stepped-lap

The double-lap joint is one of the most common of all bolted structural joints. This type of joint is well suited for a wing centerline splice which is not exposed to the airstream. It is a fairly efficient joint which is free of eccentrically induced bending stresses. It is also a relatively easy and inexpensive joint to fabricate. The balanced double-lap joint is essentially a butted joint, symmetrically spliced by two plates of equal thickness. Away from the splice, a nominal skin thickness is necessary to carry the design tensile load, but at the joint this nominal thickness is built up to a thickness which can carry the concentrated stresses at the bolts. The built-up skins are then butted together and spliced by two identical plates, each of half the thickness of the built-up skin.

The stepped-lap joint is also a joint where the nominal thickness is built up, and which is free of eccentrically induced bending stresses. But rather than having a uniform buildup spliced by a uniform splice plate, the splice plate is stepped and fitted to a matching stepped buildup as shown in Figure 66. The stepped-lap joint is a more efficient joint than the double-lap joint, but is considerably more difficult and costly to fabricate and fit. It is important to appreciate the reason for the greater efficiency of the stepped-lap joint. First of all, in the case of several bolt rows, with each row on a step, the transfer load distribution is more uniform than for the double-lap joint where the end bolts are so highly loaded. Secondly, and more significantly, the total thickness of the stepped-lap joint can be less than the double-lap joint. Where all of the load is in the buildup and it must be thickest, the splice plate need only be minimal, and conversely, when all of the load has been transferred to the splice plate, the buildup need only be minimal. As a further consequence, the bolt lengths can be shorter for the stepped-lap joint.

Single-lap joints may be either supported or unsupported. No bending stresses are assumed to exist in the supported single-lap joint, so that the structural behavior of that joint is nearly identical to a double-lap joint of half the thickness and no buildup. The support for this type joint is provided in the overlap region by connecting structure. The connecting structure can, for example, be rib flanges supporting the overlap region of a single-lap skin splice. Eccentrically induced bending stresses, do, however, exist in the unsupported single-lap joint, and these bending stresses are greatest at the two points just outside the overlap. Single-lap joints are the least expensive and easiest of all joint types to fabricate. Consequently,

the added expense and complexity of providing a joint buildup is generally rejected in favor of the inefficient uniform thickness. Of course, this thickness is considerably more than the nominal skin thickness discussed previously. Due to the extreme inefficiency of unsupported single-lap joints, their applicability should be reserved for low tensile load carrying secondary structure such as fairings, or perhaps rib and spar webs.

MATHEMATICAL PROBLEM DESCRIPTION

Development of a program which optimumly designs three of the four joint types has been completed. For a given joint loading, the number of bolt rows, bolt diameter, bolt spacing, and joint thickness are computed for the least weight joint. This search for the optimum design may be conducted for joints of the following type:

- o double-lap
- o supported single-lap
- o unsupported single-lap

For the stepped-lap joint an analysis is conducted which provides margins of safety for each bolt row with the associated failure mode for a given joint loading. The stepped-lap joint consists of too many variables for the search algorithm employed for the other three joint types.

In order to simplify the search for an optimum design, the number of independent variables must be kept to a minimum. For this reason, the math model associated with the three types of joints which considered here for optimum joint designs have the following restrictions.

- same bolt sizes for all rows
- same bolt spacing for all rows
- edge distance of 3D
- row pitch of 6D
- two compositions of graphite-epoxy material
- two bolt materials

In addition the double-lap joint is restricted to a balanced double-lap which requires that the two outer splice plates each be one-half the joint buildup thickness. Furthermore, the joint buildup is assumed to be gradual, with a slope of 15:1.

The two compositions of graphite-epoxy material were chosen to differ in the percentage of 0° plies since the stress concentration relief factors for these composite materials were found to be predominantly dependent on this percentage. The two percentages selected were 25% and 37-1/2% of the 0° plies. The 25% composition of course corresponds to the popular pseudo-isotropic layup. To date, stress concentration relief data has been accummulated for these two compositions only. Of course, the math model can be expanded to include more material compositions whenever this data becomes available.

The stepped-lap joint analysis allows for varying step lengths. Bolt diameters and bolt spacing may vary from one step to another. Step thicknesses of the splice plate and the joint buildup are independent (i.e., the joint need not be balanced). The following restrictions exist for the stepped-lap joint math model.

- bolts at center of steps
- two compositions of graphite-epoxy material
- two bolt materials

Strictly speaking, the bolts of all the rows are in line for the math models employed for the bolted joints. The coupling effects of the bolt rows has been neglected, so that the bolts in one row do not influence the stress state at another row. Therefore, the bolted joint analyses developed here are not strictly valid for stepped-bolts, but, depending on the row pitch, may not incur unreasonable error.

MATHEMATICAL DERIVATION OF SOLUTIONS

Four failure modes are treated for all of the bolted joint designs at each bolt row.

- tension at the hole
- bolt bearing
- bolt shear
- shear tear-out

Tension at the hole is frequently the dominant failure mode. The tension stress consists of two components, a tensile stress due to the bolt bearing on the hole, and a tensile stress due to a tension load running past the hole. The tension load running past the hole is the sum of the bolt loads upstream.

$$\sigma_t = K_{t1} \frac{P_t}{t(w-d)} + K_{t2} \frac{P_b}{t_e(w-d)} \qquad \ldots \quad (1)$$

$P_b = P_b \; w \; N_x$

$P_t = P_t \; w \; N_x$

K_{t1} = observed stress concentration factor associated with unloaded open hole

K_{t2} = observed stress concentration factor associated with loaded hole

The bolt loads at a given row[1] and the load running past the row are expressed as fractional parts and are denoted by P_b and P_t, respectively. In the case of double-lap and single-lap joints for which an optimum design can be obtained, a subroutine based on a curve fit[4] has been coded. For the stepped-lap joint, however, for which only an analysis is conducted, a more time consuming subroutine employing matrix inversion is used. The bolt load distribution is dependent on the flexibilities of the bolts, the joint flexibility, and the frictional force induced by tightening the bolts. The frictional forces, however, are neglected in this investigation since they depend on how far the bolts were torqued at the time of installation.

The observed stress concentration factors for composites are significantly lower than the elastic, isotropic stress concentration factors which are theoretically derived. The observed stress concentration factors are emperically derived from test data conducted for two different compositions. The two compositions tested differ in the percentages of 0° plies.

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1. Hart-Smith, L. J., "Adhesive-Bonded Double Joints", NASA CR-112235, January 1973.

4. Yen, S. W., "Investigation of Load Distribution Among Fasteners in a Multiple Row Double-Cover Butt Joint", MDC J5049-01 Douglas Aircraft Company Report, 1971.

25% 0° plies

$$K_{t1} = .5967 - .2331\ d + (.4033 + .2331\ d)\ K_{t1_e}$$

$$K_{t2} = .7311 - .1554\ d + (.2689 + .1554\ d)\ K_{t2_e}$$

37-1/2% 0°-plies

$$K_{t1} = .3923 - .3512\ d + (.6077 + .3512\ d)\ K_{t1_e}$$

$$K_{t2} = .5949 - .2341\ d + (.4051 + .2341\ d)\ K_{t2_e}$$

These expressions differ somewhat from those given in reference 1, due to the inclusion of a size effect which is introduced by the diameter, d. It should be noted that the above expressions are based on very limited data, especially with respect to the size effect. As more data becomes available, these expressions should be updated accordingly. The elastic, isotropic stress concentration factors associated with loaded and open holes are denoted in the above expression as K_{t1_e} and K_{t2_e} respectively. They are presented in reference 1 and are theoretically derived.

$$K_{t1_e} = 2 + (1 - d/w)^3$$

$$K_{t2_e} = 2 + (w/d - 1) - 1.5\ \frac{(w/d - 1)}{(w/d + 1)}\ \theta$$

$$\theta = 1.5 - .5/(e/w) \qquad \text{for } e/w < 1$$

$$\theta = 1.0 \qquad \text{for } e/w \geq 1$$

The effective thickness which is assumed to react the bearing stresses at the loaded holes is not allowed to exceed the bolt diameter. Although this demand is rather severe and perhaps overly conservative, some limitation is necessary to account for bolt bending and a host of other nebulous effects. Mathematically, the effective thickness is defined by

$$t_e = t \qquad \text{for } t \leq d$$

$$t_e = d \qquad \text{for } t > d$$

For the case of the unsupported single-lap bolted joint, there is an additional amount of tension at the hole, caused by eccentrically induced bending stresses. This bending stress is derived[1] for the case of bonded joints and is a maximum at the edges of the bonded overlap. The bending stresses[1] are assumed for the case of bolted joints, but with an overlap distance of 2C taken as the distance between the outer rows of bolts.

$$\sigma_b = \frac{6M_o}{t^2} \qquad \ldots \quad (2)$$

$$M_o = KN_x\, t/2$$

$$K = \frac{1}{1 + \xi C + \frac{1}{6}\xi^2 C^2}$$

$$\xi^2 = D_x N_x = \frac{12(1-\upsilon^2)}{Et^3} N_x$$

1. Hart-Smith, L. J., "Adhesive-Bonded Single-Lap Joints", NASA CR-112236, 1973.

If the sum of equations (1) and (2) is set equal to the allowable tensile stress, F_{tu}, the allowable joint load, N_x, associated with a tensile mode of failure can be determined as

$$N_x = \frac{F_{tu} t \ (1-d/w)}{P_t K_{t1} + P_b \frac{t}{t_e} K_{t2} + 3K\ (1-d/w)} \qquad \ldots \ (3)$$

Since the values of P_t and P_b represent fractional parts of N_x which bypass the bolts and are transferred by the bolts of a particular row, the values of N_x computed from equation (3) vary from row to row. In other words, this value of N_x represents the maximum joint loading which can be applied before the tensile stresses at a particular bolt row exceed the allowable tenile stress.

The maximum loading which can be applied before the bearing stress at a particular bolt row exceeds the allowable bearing stress is determined from

$$N_x = \frac{F_{br} t}{P_b} \ \frac{d}{w} \qquad \ldots \ (4)$$

The maximum loading which can be applied before a bolt shear failure occurs at a particular bolt row is determined from

$$N_x = \frac{\pi}{2} \ \frac{F_{su}\ (\text{bolt})\ d}{P_b} \ \frac{d}{w} \qquad \ldots \ (5)$$

In the case of single-lap joints, N_x should be limited to half the value of equation (5), which is based on double shear. The maximum loading which can be applied before a shear tear-out failure occurs at a particular bolt row is determined from

$$N_x = 2(e/d - .5) \frac{F_{su} t}{P_b} \frac{d}{w} \qquad \ldots (6)$$

where the edge distance e/d = 3 is used. It should be noted that this formula is valid only when there are sufficient cross plies as in the case for the two composite mixes considered here. With an insufficient number of cross plies, it is pointed out[5] that no amount of edge distance will prevent shear tear-out.

Finally, for each bolt row, there are four computed values of N_x computed from equations (3) thru (6), each associated with a failure mode. Denoting the maximum of these four values as $\bar{N}_x$, the margin of safety for a particular bolt row is expressed in terms of the applied joint load, N_x, by

$$M.S. = \frac{\bar{N}_x}{n_x} - 1 \qquad \ldots (7)$$

The allowable joint load is then that values of n_x which yields a M.S. = 0.00 for one of the bolt rows.

The joint weights which are minimized are actually weight penalties. The weight penalty of a joint is the additional weight due to the joint's splicing function. For the single-lap joint, it consists of the weight associated with one of the thicknesses extending over the overlap distance, less the bolt holes thru both thicknesses, plus the weight of the bolts themselves. For the

5. Hart-Smith, L. J., "Bolted Joints in Graphite-Epoxy Composites", NASA CR-144899, 1977.

stepped lap and bolted lap joints, the weight penalty consists of the weight of the joint buildup, less the nominal thickness, less the bolt holes, plus the bolts themselves. It should be noted that a comparison of a single-lap joint weight with a double-lap joint weight is unfair since the single-lap joint is not built up and the advantage of reduced nominal stresses is not utilized.

DESCRIPTION OF NUMERICAL METHODS

The search algorithm employed for determining an optimum joint design is a direct brute-force search procedure. The number of bolt rows is incremented from one to four. The diameter is incremented in sixteenths from 3/16 to 1-1/2. For each combination of bolt diameter and number of bolt rows, the thickness, t, and the w/d ratio are determined for minimum joint weight.

From equation (5)

$$N_x \leq \frac{\pi}{2} \frac{F_{su}\,(\text{bolt})\, d}{P_{b_{max}}} \frac{d}{w}$$

so that an upper bound for w/d is

$$w/d \leq \frac{\pi}{2} \frac{F_{su}\,(\text{bolt})\, d}{N_x\, P_{b_{max}}}$$

The lower bound for w/d depends on whether a bearing design is demanded. When that is the case, from equations (3) and (4)

$$\frac{tF_{tu}\,(1 - d/w)}{P_t\, K_{t1} + P_b\, t/_{tc}\, K_{t2} + 3K\,(1 - d/w)} \geq \frac{tF_{br}}{P_b}\, d/w \geq n_x$$

The lower bound on w/d can be determined by solving these two inequalities for w/d and t simultaneously with an iterative process. That this process does indeed lead to a lower bound on w/d can at least be seen immediately for other than the unsupported single-lap joint. The first inequality leads to

$$w/d \geq \frac{F_{br}}{F_{tu}} \left({}^{P}t/_{P_b} \quad K_{t1} + t/_{tc} \quad K_{t2} \right) + 1$$

In addition to the above constraints imposed on w/d, the following practical limits on the feasible range of w/d have been observed.

$$3 \leq w/d \leq 12$$

With the range on w/d thus defined, the value of w/d which produces the least weight joint is computed using a quadratic interpolation routine. Thus for any combination of bolt diameter, d, and number of bolt rows, m, the value of w/d and t are determined. This then represents one feasible design, and there are as many as 88 of these feasible designs. The optimum design is then taken as the one with the least joint weight.

LIMITATIONS:

Although most of the limitations associated with the math model have already been noted, they are reported here for sake of completeness.

Double-Lap Joint

- maximum of 4 bolt rows
- $3/16 \leq$ bolt dia. $\leq 1\text{-}1/2$ (in 1/16 increments)
- two compositions of graphite epoxy material
  - 25% 0° plies
  - 37-1/2% 0° plies
- two bolt materials
  - steel
  - titanium
- same bolt sizes for all rows
- same bolt spacing for all rows
- edge distance of 3D
- row pitch of 6D
- balanced joint
- slope for joint buildup of 15:1
- $3 \leq w/d \leq 12$

Stepped-Lap Joint

- maximum of 9 bolt rows
- $3/16 \leq$ bolt dia. $\leq 1\text{-}1/2$ (in 1/16 increments)
- two compositions of graphite-epoxy material
  - 25% 0° plies
  - 37-1/2% 0° plies
- two bolt materials
  - steel
  - titanium
- bolt rows at center of steps
- slope for buildup of 15:1
- $3 \leq w/d \leq 12$

Single-Lap Joint

- o maximum of 4 bolt rows
- o $3/16 \leq$ bolt dia. $\leq 1\text{-}1/2$ (in 1/16 increments)
- o two compositions of graphite-epoxy material
  - 25% 0° plies
  - 37-1/2% 0° plies
- o two bolt materials
  - steel
  - titanium
- o same bolt sizes for all rows
- o same bolt spacing for all rows
- o edge distance of 3D
- o row pitch of 6D
- o equal thicknesses
- o no buildup
- o $3 \leq w/d \leq 12$

Many of the above range restrictions are due to very limited test data. These restrictions can be reduced as more complete test data becomes available. With the above limitations, a ceiling on joint loads of about n_x = 40,000 lb. per inch should be observed. Designs for greater joint loadings may become questionable and impractical.

Although many test cases of bolted joints were run for checkout purposes, future runs may indicate limitations not presently appreciated. Additional limitations may conceivably be required for the iteration and interpolation algorithms which are used, even though these codes have proved successful for all the checkout cases run to date.

The joint computer programs have been run with both IBM and CDC single precision accuracy with no problems.

SOLUTION ACCURACY

The most vulnerable area to inaccuracy of the solution is the test data which formed the basis of the observed stress concentration factors. For example, the size effect in these expressions was determined from results of only two bolt diameters. Also, the weight of the bolts is subject to some error, depending on the type of bolt and nut combination used. The effective thickness used to react bolt bearing may be a source of considerable conservation. The overall accuracy of the analytic solutions presented here are assumed to be adequate for the four types of bolted joints covered.

DEFINITION OF NOTATION

w	bolt spacing, inches
d	bolt diameter, inches
t	joint thickness (builtup, where applicable), inches
N_x	allowable joint load, lbs. per inch
n_x	applied joint load, lbs. per inch
F_{br}	ultimate bearing stress allowable, PSI
F_{tu}	ultimate tensile stress allowable, PSI
$F_{su_{bolts}}$	ultimate bolt shear stress allowable, PSI
F_{su}	ultimate joint shear stress allowable, PSI
e	edge distance, inches
K_{t1}	observed stress concentration factor for open hole
K_{t2}	observed stress concentration factor for loaded hole
K_{t1_e}	elastic stress concentration factor for open hole
K_{t2_e}	elastic stress concentration factor for loaded hole
P_b	fractional part of loading transferred by bolt
P_t	fractional part of loading running past the hole
t_e	effective thickness reacting bolt bearing, inches
M_o	bending moment at edge of overlap, in/lbs. per inch
K	bending moment coefficient for single-lap joint M_o

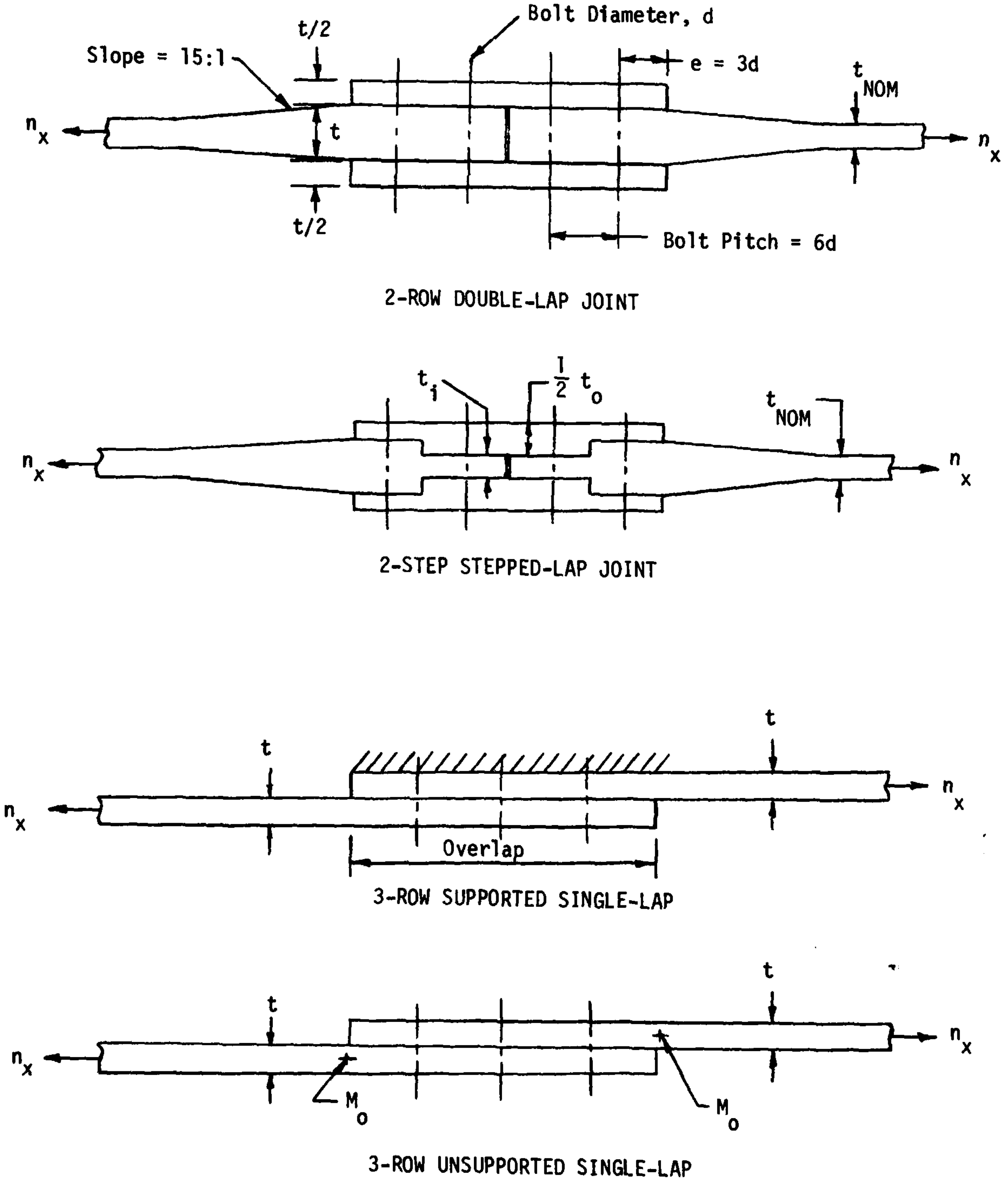

Figure 66. Bolted Joints

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